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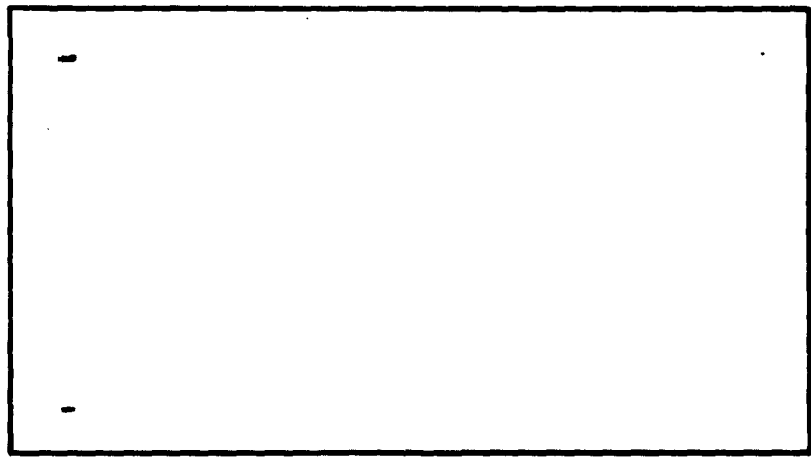
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THESIS

Presented to the Faculty of the School of Engineering

The Institute of Technology

Air University

in Partial Fulfillment of the

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in Electrical Engineering

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ALTITUDE INFORMATION
and TACTICAL AIR NAVIGATION

by

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GE/EE/62-19

Graduate Electronics
December 1962

Preface

This report presents the findings of my attempt to simplify the problems of Air Traffic Control by encoding altitude information and transmitting it to the ground. The study has been both interesting and rewarding—especially since most of my military duty has been directly associated with instrument flying and therefore Air Traffic Control.

I gratefully acknowledge the effort and patience required of Mr. C. E. Mutters of the Instrument Repair Unit, Electronics and Armament Section, and Mr. L. G. Coffelt of the Electronic-Mechanical Branch, Directorate of Test Data, Wright-Patterson AFB, Ohio, who assisted with the altimeter modification. For the use of their digital logic circuits and other laboratory assistance I am indebted to Mr. R. E. Conklin and other members of the Bionics and Computer Branch, Electronics Technology Laboratory, Wright-Patterson AFB, Ohio. Also, I would like to thank Mr. M. W. Corbin and the personnel of the Electrical Engineering laboratories at the Air Force Institute of Technology for their understanding and assistance in procuring certain necessary supplies.

Finally, it is with sincere indebtedness that I thank Professor J. H. Johnson and Capt. M. Kabrisky of the Electrical Engineering Department for their guidance in this undertaking.

<div align="right">James A. Schmitendorf</div>

Contents

List of Figures

List of Abbreviations

AGACS   Automatic Ground-Airborne Communications System

ATC   Air Traffic Control

DME   Distance Measuring Equipment

FAA   Federal Aviation Agency

GE   General Electric

ICAO   International Civilian Aviation Organization

NAFEC   National Aviation Facilities Experimental Center

TACAN   Tactical Air Navigation

VOR   Very High Frequency Omni Range

Abstract

Improvements in Air Traffic Control electronics are long overdue, partly because of the costs involved and partly because of disagreement between the agencies affected. One of the most pressing, immediate problems in providing the safe flow of air traffic is to provide ground controlling personnel with current altitude information from each aircraft.

This thesis discusses how to provide an altitude encoder for the private or business aircraft owner who can least afford the complicated equipment used by the military and airlines. Also considered is a method of transmitting the encoded altitude to ground controllers by means of superimposing altitude information with distance measuring interrogation signals.

Two altitude sensing instruments were considered for encoding. A mercury manometer was demonstrated to be feasible for the job but it was not practical due to its large size. The standard aneroid altimeter was shown to be both feasible and practical as modified to serve an additional function as an encoder.

A Kollsman altimeter was modified for optical altitude encoding at a cost of approximately $50. A digital logic circuit was devised for transferring the altitude information to a military Tactical Air Navigation (TACAN) transmitter and the transmitter was modified to send out altitude information while retaining its normal distance measuring interrogation function.

Distance Measuring Equipment (DME) was chosen as a transmission media to eliminate a need for "two" 1000 megacycle transmitters and receivers

on small aircraft, i.e. one for DME and one for a radar transponder. The Federal Aviation Agency presently leans toward using the radar transponder for altitude transmission.

This thesis has provided the techniques and has demonstrated the feasibility of encoding altitude information using standard aircraft equipment and transmitting such information via the DME portion of TACAN. Thus it is concluded that light aircraft can be included in future electronic Air Traffic Control improvements.

James A. Schmitendorf

I. Introduction

The need for strict surveillance and control of aircraft under instrument flying conditions has long been obvious to both pilots and controlling personnel on the ground. Air disasters such as those over the Grand Canyon and Brooklyn have, at last, made the problem quite apparent to the public. This, in turn, has induced Congress to spend more money on Federal Air Traffic Control.

The Federal Government has charged the Federal Aviation Agency (FAA) with the responsibility of air traffic control in the United States and also with the research, development, and standardization of the scientific techniques with which it is to be accomplished. Internationally, these same functions are accomplished by the International Civilian Aviation Organization (ICAO).

At the present time air traffic control is monitored over a structure of airways (much like a road map) by UHF and VHF radio transmissions between pilot and controller personnel. The controlling personnel reside in a complicated network of Air Traffic Control Centers, Approach Control facilities, and Airport Control Towers, all interconnected by telegraph and telephone. The basic aids which are used by the pilot to determine aircraft position in relation to airways and landing facilities are radio beacons of various kinds, radio conversations with radar controllers, and distance measuring equipment. The ground personnel have at their disposal, the airway on which an aircraft is flying, periodical reports from pilots, and in most cases radar with which to follow an aircraft's progress.

1

Although the system outlined might seem adequate, the advent of more and more aircraft plus their greater speed and altitude have made the problems of air traffic control an exceedingly difficult one. To add to the perplexity a great many entities must be in agreement as to changes in air traffic control, i.e., ICAO, Congress, FAA, the airlines, the military, the private aircraft owners, and the pilots themselves, must all be consulted and generally satisfied (Ref. 5). These are some of the reasons why the modernization of air traffic control has lagged behind the technology adequate for proper control.

It was realized after World War II that periodic voice transmitted position reports were not adequate for air traffic control, especially in terminal control areas, and the use of radar was initiated. At about the same time, Very High Frequency Omni Range (VOR) stations began to take the place of Low Frequency Radio Ranges. A VOR is a ground transmitter whose signals, when received by certain airborne equipment, enable the pilot to fly an aircraft on a selected magnetic course.

In the preceding decade the radar transponder and Tactical Air Navigation facilities (TACAN) were developed. A radar transponder operates as follows. The ground controller via voice communications requests the pilot to select a certain code on his airborne transponder. The ground station then initiates an electronic interrogation and the aircraft transponder automatically responds. The radar surveillance scope displays a series of bright "bars" near the target interrogated. TACAN, on the other hand, is basically a navigation radio beacon aid much the same as VOR; however, it also includes a transmitter which is capable of interrogating the ground station, measures the time until reply, and thereby

2

determines distance to the ground beacon. The distance function of
TACAN may be a discrete piece of airborne equipment, and is known as
Distance Measuring Equipment (DME). It should be noted in passing that
an aircraft equipped with both a radar transponder and DME has "two"
transmitters in the 1000 megacycle range.

Two systems are under development by the Federal Aviation Agency's
National Aviation Facilities Experimental Center (NAFEC) in the field of
altitude telemetry. One of these projects includes a complicated data
link system using the air communications UHF frequency band and includes
several other air traffic control functions in addition to altitude
information. The system is called Automatic Ground-Airborne Communications
System (AGACS) and was developed by the Radio Corporation of America.
This system necessarily reduces the frequency spectrum available for
voice communications.

The second project concerns the inclusion of altitude coding with
the radar transponder. This proposed project is an extension of the
present radar transponder system by including an altitude display near
or directly on the controller's radar scope. The disadvantages of this
approach necessarily include the disadvantages of radar: (1) radar is
expensive to procure and maintain, (2) it was basically conceived to
detect "unfriendly" or "uncooperative" aircraft targets, (3) it is often
unable to distinguish small aircraft or aircraft near the ground, (4) radar
cannot distinguish the identity between two targets without the use of
other radio communications, and (5) it is susceptible to atmospheric
interference, e.g. thunderstorms. It is felt that there are more economical
and expeditious methods available for performing the functions now performed

3

by surveillance radar. It does not seem reasonable to use radar if a radar transponder is also required.

As early as 1956, before FAA was established, the United States Navy let a contract to the International Telephone and Telegraph Corporation for the development of a data link system much the same as AGACS mentioned previously. This system was to be incorporated with the Tactical Air Navigation system (TACAN) which this corporation had developed earlier and came into wide usage in 1959.

Reasons (other than political) as to why the TACAN data link was never accepted, either by military or civil authorities, are difficult to establish. The author has concluded from the literature (Ref. 7) that the only technological deficiencies of the TACAN data link proposal were the use of pulse position modulation rather than pulse code modulation and the display of the air traffic control information on dials and meters rather than a cathode ray tube or scope.

In this brief introduction an attempt has been made to familiarize the reader with air traffic control. The first paragraph emphasizes the immediate need for providing safe, reliable, altitude information to the controlling agencies on the ground. The purpose of this investigation was to build an altitude encoding device and to consider a method of transmitting the information.

II. The Problem

In August of 1962 the author visited the National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, New Jersey to obtain the latest developments in altitude telemetry and establish a precise thesis topic. Here it was learned from Mr. George Mahnken that a problem existed in reducing the cost of altitude encoders from 2000 dollars to the 500 dollar range. Such a reduction would allow not only the air carriers and military to take part in the modernization of air traffic control but also the private aircraft owners. This is a portion of the chosen problem, but instead of sending altitude information to the ground via the radar transponder as NAFEC has done, the author has chosen to use TACAN (Fig. 1). The thesis problem can be stated as the design and testing of an economical low altitude encoder and the multiplexing of this information with the TACAN distance measuring interrogation signals.

Few assumptions are required concerning the altitude encoder but some must be made concerning the use of TACAN for a transmission media. It must be assumed that "large," "fast," digital computers will be installed in all Air Traffic Control Centers in the near future for the purpose of ; (1) updating and predicting flight progress, (2) calculating collision avoidance information plus the corrective measures required, and (3) expediting the transfer of aircraft between air traffic control centers. A portion of these functions, the updating of flight progress strips, is already being handled by UNIVAC computers in most ATC Centers. It is also assumed that the availability of current altitude and a minimum of "other functions" can be manipulated and displayed by the assumed

Figure 1 Complete System Diagram Using
Automatic Altitude Information and TACAN
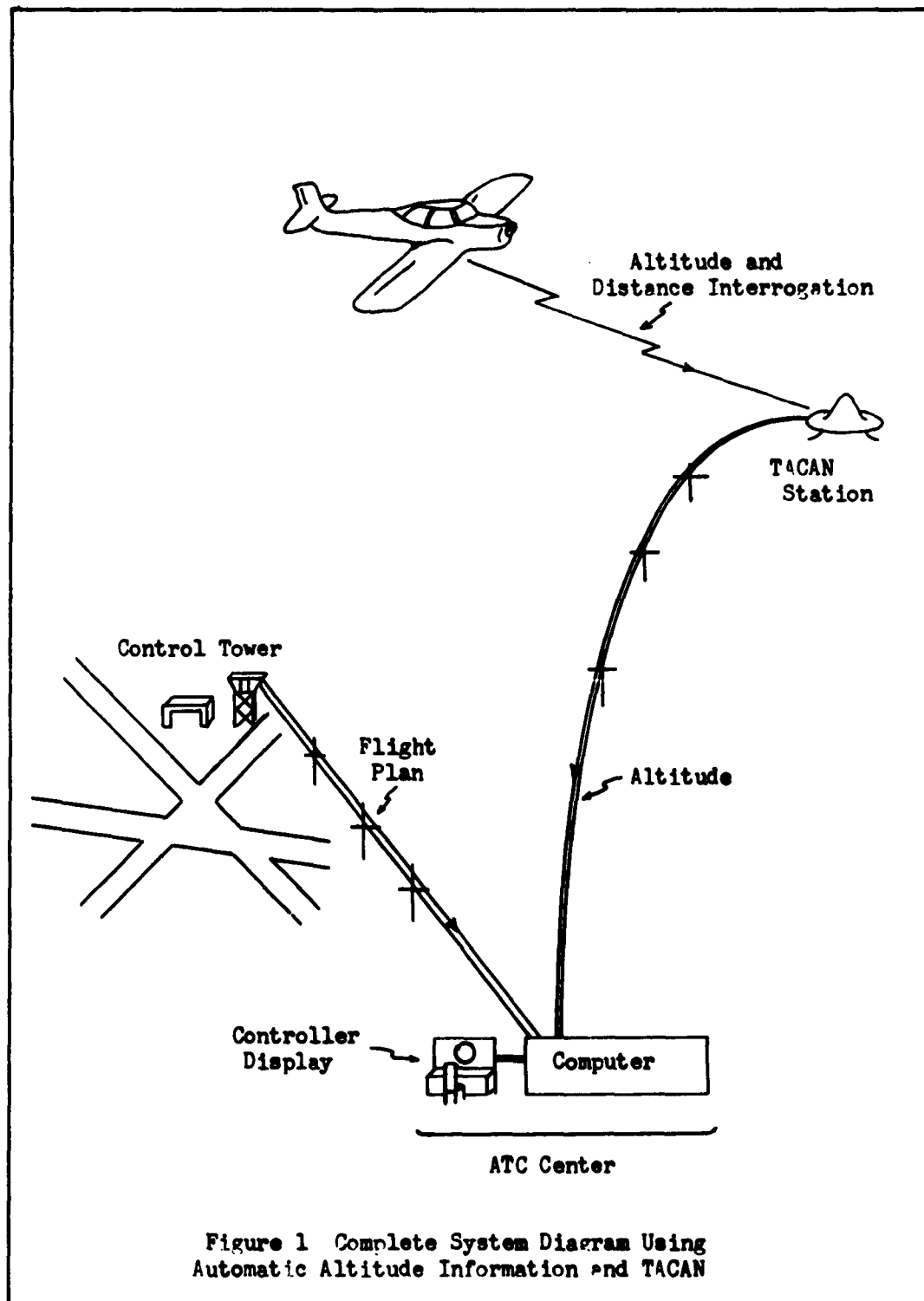
computer to effect air traffic control. The words "other functions" refer to some method of determining which aircraft is sending which altitude. This is not part of the thesis problem but is quite necessary for system effectiveness and possible solutions will be discussed in the final chapter under recommendations for further study.

The last part of this chapter tries to further justify the use of TACAN as an air to ground communications link. First, however, some of the accepted criteria for aircraft communications equipment design will be listed:

1. The airborne equipment should be kept as economical as possible.

2. The airborne equipment must be simple enough to permit high reliability.

3. The various using agencies, airlines, military, etc., must all be consulted concerning design proposals.

4. The work load of the crew members can not be greatly increased or complicated.

5. As much of the weight and volume of the equipment as possible should be kept on the ground.

6. Any standardization established by ICAO or FAA should be incorporated.

7. The design should utilize available equipment already in operation whenever feasible.

8. The frequency spectrum is already overcrowded and little if any new frequency space can be allocated.

9. New equipment must be integrated into the ATC system without requiring any decrease of operations.

7

The reasons for choosing to incorporate altitude signals on the distance measuring signals of TACAN are now listed for comparison with the above criteria:

1. The modifications to the airborne DME and the ground TACAN station should be more economical than the similiar modification required for the inclusion of altitude in radar beacon equipment.

2. Relatively few changes are required in the airborne DME to make maximum utilization of the existing equipment, and the reliability of the system should not be greatly affected.

3. The pilot need not select his identity code as required in radar beacon transponders. The altitude information is transmitted from the aircraft continuously and need not be requested by the controller.

4. Distance Measuring Equipment is in use at the present time by the majority of military and air carrier aircraft and is becoming available at lower prices to private aircraft owners.

This chapter should have made the engineering problem clear, i.e. to first consider methods of encoding low altitude information in an economical manner and to secondly consider a modification scheme for sending altitude information from air to ground multiplexed with TACAN DME.

III. Encoding Devices

One goal of this thesis is to select an economical method of
altitude encoding for low flying aircraft. Using the ICAO standardized
"gray" or "hybrid" code at 500 foot intervals the low altitude airway
structure (below 14,500 ft.) can be encoded with five binary "bits"
(Table 1, Chapter 5). The complete code is given in Appendix A.
Different agencies have argued for 100 foot increment encoding but this
is not practical for the following reasons: (1) Pilots do not maintain
their desired altitude exactly but may deviate by as much as 100 feet.
(2) Low cost altimeters are relatively inaccurate, plus or minus 275 feet
at 15,000 feet. (3) The altitudes flown on instrument flight plans are
always thousands of feet or thousands plus 500 feet (e.g., 1000, 1500,
2000, 2500, etc.); therefore, the ground controllers would have no need
for 100 foot interval information except possibly to obtain a more
accurate rate of change of altitude. Considering the extra equipment
necessary for 100 foot interval encoding and the inaccuracies cited,
500 foot intervals seem well justified.

With interval increments decided, attention can be focused on the
mercury manometer and pressure sensitive aneroid as potentially useable
encoding devices. The mercury manometer is a "U" shaped glass tube used
to very accurately measure pressure differentials. A single tube
version and sump configuration is employed by weather forecasters to
measure changes in atmospheric pressure. Pressure data is gathered and
used in weather forecasting and by pilots to update the Kollsman scale
on aircraft altimeters. Since the mercury manometer, or barometer, is

often used as a source of accurate pressure measurements an investigation was made to determine if an airborne altitude encoding device of this type would be feasible.

By placing kovar* wires through the glass tubing at calibrated levels a digital encoded mechanism is readily obtained. Necessary encoding circuits include a grounding wire in the bottom bend of the "U" shaped manometer, an astable multivibrator to excite one side of all the horizontal encoding wires and five "or" logic devices using approximately eighty diodes. In operation the multivibrator completes a circuit only to those "or" gates connected to wires above the mercury level in the tube.

All manometers that are evacuated completely on one end and used to measure atmospheric pressure are necessarily at least 30 inches long. For a low altitude encoder the difficulty of excessive length may be overcome by evacuating only a portion of the encoding side of the glass tube (to approximately one half atmosphere) and thereby reducing the tube size to half its normal length. Such a procedure would decrease the distance between the encoding wires and slightly increase the inaccuracies of the measurements. In order to vary the pressure in the measuring portion of the tube for daily changes in pressure the volume of the airspace above the mercury column may be changed. This method for field pressure correction would work in much the same manner as it

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* A type of metal which mercury will not corrode and can be attached to glass.

11

presently does for the aircraft altimeter and could even be mechanically linked to the altimeter setting correction knob. Such correction devices might prove to be unnecessary since some agencies would prefer to standardize a fixed reference pressure of 29.92 inches of mercury for all altitude encoders.

It appears at first that a mercury manometer would be highly susceptible to inaccuracies due to aircraft vibration and gusty air; however, quite to the contrary, a flight conducted on 4 August 1962 in C-47 Number 49421 using a manometer without encoding wires showed no variation in the mercury column visible to the naked eye, even in relatively turbulent air. The only adverse effect noticed was a pendulum like fore and aft swinging action at a very low frequency. It should be noted in the discussion of accuracy that errors due to altitude gravitational effects and capillarity depression can be corrected by proper scale calibration and placement of the encoding wires.

This leaves only two principle sources of error, scale error and imperfect vacuum. A conversation with a scientific glass-blower at the Aeronautical Research Laboratory, Wright-Patterson AFB on 10 August 1962 revealed that the largest source of error would most likely be the disturbance to the inside glass walls of the manometer while inserting the kovar wires. The wires themselves can be made extremely small with a cusp on the lower side to reduce surface tension and facilitate meniscus break away. Moreover, since an aircraft flies at 500 foot levels the action of the encoder at the wire level is not extremely critical. In order to receive a steady reading of altitude the wires would be set at 500 foot increments at 250 and 750 foot levels (e.g. a wire at the 750

12

foot level and the 1250 foot level would produce readings of 500 feet and 1000 feet respectively, etc.). More advantages of using mercury as a pressure measuring agent and the accuracies attainable are given by A. Pool (Ref. 4:11A5-11). The cost of the above described equipment, including a five bit storage unit for the output of the "or" gates should be less than $250.

The following list outlines the main disadvantages of a mercury manometer:

1. Height limitation: The mercury manometer has an absolute ceiling limitation because the lower temperatures at higher altitudes begin to solidify the mercury (approximately 20,000 feet).

2. Extra equipment: A rather large (approximately 17" x 10" x 4") remotely located and vibrationally isolated equipment box would be required for the airborne installation. This box would need a static source plus voltage input and output wires. The large width dimension (10 inches) is required to allow the pendulum mounted manometer to seek the vertical while the aircraft is climbing and descending. Low frequency oscillations of the pendulum requires a properly adjusted damper. The weight of the extra equipment is in the order of three or four pounds.

It is felt at this time that the size of the extra equipment is the only item restraining the mercury manometer from becoming an inexpensive low altitude encoder. But for this reason alone the mercury manometer will not be further considered. A pilot model of this encoder was not

13

constructed.

The second device considered for an economical altitude encoder was the aneroid. An aneroid is a small, sealed, metal enclosure which expands when the surrounding pressure decreases. The expansion of the metal enclosure is transformed with suitable gearing to rotate a dial. This mechanism, known as the altimeter, is normally used in all aircraft.

Because all aircraft already have altimeters, a great saving may be realized if the altimeter can be modified in a simple fashion to provide altitude encoding. Several companies (Kollsman Instrument Corp., Electronic Assistance Corp., and others) have been working on methods of altitude encoding using the aneroid. The Federal Aviation Agency has let several contracts in conjunction with project "SLATE", which concerns the development of a general aviation altitude encoder and radar transponder. To date the majority of the encoders developed have utilized a rotating circular encoding disc, driven by an aneroid pressure sensing mechanism, with the output taken from tiny brushes making electrical contact at the encoding wheel. Perhaps the greatest disadvantage of this method is the friction created between the brushes and the encoding disc. A further disadvantage is that the brushes are extremely fragile. A similiar encoding scheme (Ref. 8) uses a light source to excite sensitive photo cells. The encoding is accomplished by shining light through an aneroid driven rotating disc. The disc is alternately opague and transparent in a series of circular arcs. The latter method, using the optical encoder, was chosen in this project because of the undesirability of the brushes and will be described in detail.

14

IV. Altimeter Modification

Since the altimeter is already available in all aircraft and uses the aneroid for pressure sensing, it was decided not to duplicate the device but simply add to it the function of altitude encoding. If the light aircraft owner could buy in "kit" form the necessary items to convert his present altimeter into an altitude encoder and still retain a normal altimeter, then he would certainly be more willing to cooperate with the modernization of air traffic control.

To attempt the above scheme a used 50,000 foot, C-12, Kollsman altimeter was obtained (Figs. 2 and 3). In Chapter 3 the decision was made to use an optical encoding rotating disc for changing analog information into digital information. Problems associated with the altimeter modification were: (1) deciding where to mount the rotating encoding disc, (2) choosing the type of optical detectors, (3) determining the type of light source to use and where to mount it, and (4) getting the digital encoded information out of the sealed altimeter case. All of these interrelated problems had to be solved keeping in mind that the altimeter was to be used in the normal manner by the pilot.

Before discussing how these problems were solved it is necessary to briefly consider what is to be used as an altitude reference. As mentioned previously, many agencies have decided to use 29.92 inches of mercury as a standard pressure reference for altitude encoders. This is quite acceptable for the higher airway structures; however, for the low airway structure this procedure is unrealistic. If 29.92 were the reference of a low altitude encoder it is conceivable that the controller

Figure 2 —Exploded View—Sensitive Altimeter

1. Case Assembly
2. Ring—Case snap
3. Ring—Spring
4. Movement Assembly
5. Bracket—Cover Assembly
6. Bracket—Inner Assembly—Top plate
7. Bracket—Top plate snap
8. Gear Assembly—Top plate mounting
9. Gear Assembly—Idler

10. Gear Assembly—Inner setting mark drive
11. Gear Assembly—Barometric dial drive
12. Gear Assembly—Inner setting mark
13. Dial Assembly—Barometric
14. Spacer—Wheel spacer
15. Ring
16. Dial
17. Pin—Dial locating
18. Screw—Dial

20. Ring—Setting (outer setting mark)
21. Ring Assembly—Gasket centering
22. Head—Third
23. Head Assembly—Intermediate
24. Head Assembly—Large
25. Gasket—Sealing
26. Glass
27. Gasket—Paper
28. Washer—Rear
29. Spring

30. Washer—Front
31. Plate—Mounting flange screw lock
32. Washer—Mounting flange
33. Screw—Mounting flange
34. Screw—Mounting flange
35. Seal—Mounting flange seal
36. Seal—Locking
37. Screw—Locking end
38. Nut—Knob lock
39. Knob

16

Figure 3 —Exploded View—Sensitive Altimeter Mechanism

1. Body Assembly—Mechanism
1A. Body and Hairspring Post Assembly—Mechanism
1B. Jewel—Large
1C. Jewel—Small
1D. Screw—Balance clamping
1E. Screw—Pivot
1F. Screw—Diaphragm clamping
1G. Screw—Jewel clamping
2. Shaft Assembly—Rocking
2A. Shaft—Rocking
2B. Pivot
2C. Sector
2D. Counterweight—Sector
2E. Screw—Balance clamping
2F. Hairspring
2G. Screw—Adjusting clamp
3. Pinion—Handstaff
4. Spring Assembly—Handstaff jewel
5. Wheel and Hairspring Assembly
5A. Wheel
5A1. Wheel
5A2. Pinion—Intermediate
5A3. Guard—Sector
5B. Disc
5C. Hairspring
6. Spring Assembly—Wheel jewel
7. Bridge Assembly
7A. Bridge and Hairspring Post Assembly
8. Screw—Bridge mounting

9. Pin—Taper
10. Diaphragm Unit—Range compensated
11. Arm and Balance Assembly—Calibration
11A. Balance Assembly
11B. Link—Balance
11C. Arm—Calibration
11D. Pin—Bearing
12. Link (type 940) 12. Link (type 671CPU)
12. Link (type 709)
13. Pin—Taper
14. Plate Assembly—Top
15. Wheel Assembly—Top plate mechanism
16. Plate Assembly—Top bearing
16A. Plate and Bushing Assembly—Top bearing
16B. Handstaff (short hand)
16C. Wheel Assembly
16D. Wheel and Hub Assembly—Intermediate
16E. Pinion—Intermediate
17. Screw—Bearing Plate
18. Hub and Wheel Assembly—Third hand
19. Case
20. Gear—Idler
21. Washer—Spring
22. Shaft—Idler
23. Pinion—Adjustment knob stem
24. Washer
25. Stem—Adjustment knob
26. Pin
27. Spring—Ring

17

would receive an altitude below ground level or even sea level. It
might be argued that the ground computer could correct the 29.92
reference to field pressure reference to give the controller a realistic
altitude, but to do this would add more equipment and duplicate a
function already performed by the pilot. It is the author's opinion
therefore that the field barometric pressure or mean sea level pressure
should be used for an altitude encoding reference in the low altitude
airway structure.

Using the field pressure reference eliminates any simple method of
mounting the rotating disc at the rear of the altimeter since practically
the entire inner mechanism (Item 4, Fig. 2) rotates when the Kollsman
window field barometric pressure is changed. This dilemma requires that
the rotating disc be located in the front assembly.

The frontal position of the encoding disc did complicate the optical
problems. Most commercially available photo-junction cells come in
rather large encasements and to use them would have required an extension
on the front of the altimeter case and also an extension of the handstaff
(Item 3, Fig. 3). To extend the handstaff was not feasible because the
large hand assembly (Item 24, Fig. 2) would certainly have caused the
handstaff to bend. It was therefore decided that lead sulfide photo-
junction cells or silicon photo-voltaic cells should be used. Lead
sulfide cells are available in extremely small sizes (1 millimeter square)
and could be used for high altitude encoders where more "bits" are required.
For the low altitude, five "bit" encoder, silicon photo-voltaic solar
cells are available in sufficiently small sizes and are less expensive
than lead sulfide cells.

18

GE/EE/62-19

Figure 4 shows one of the Hoffman C-58 photo-voltaic solar cells lying in front of the altimeter case and five mounted inside the case. These solar cells, encapsulated and with leads attached, retailed for $1.95 each. Specifications and graphs (courtesy of Hoffman Corp.) are in Appendix B.

To allow slightly more area for each solar cell or "bit" position, the gear ratios (Item 16, Fig. 3) were changed to make a 20,000 foot altimeter. This was easily accomplished by using items 16A through 16E from a Kollsman manifold pressure gauge. The encoding disc (Fig. 4) was fashioned to double as the slow hand and rotates one revolution each 20,000 feet while the fast hand rotates one revolution each 1000 feet.

Notice in Figure 4 that the detectors are not placed side by side in a radial array as is often the case. The cells were dispersed so that the light impinging upon one detector will not be of sufficient strength to be detected by an adjacent cell. Also, the construction of the rotating disc was made so that high resolution was obtained when rotating from an opaque to transparent position and vice versa. The disc was made of lucite with photographed encoder sheets on either side. The photographed "positives" were one-fourth the size originally drawn.

Because the solar cells are independently located, either five individual lights or one large light source may be used. To simulate aircraft instrument lighting five small G.E. No. 222 bulbs were used. These bulbs, like those on most soldering irons, have a small convex lens in the end to give some focusing. The question then arose as to how the device will work at night when white light is undesireable in the cockpit. However, since the peak of the solar cells response curve
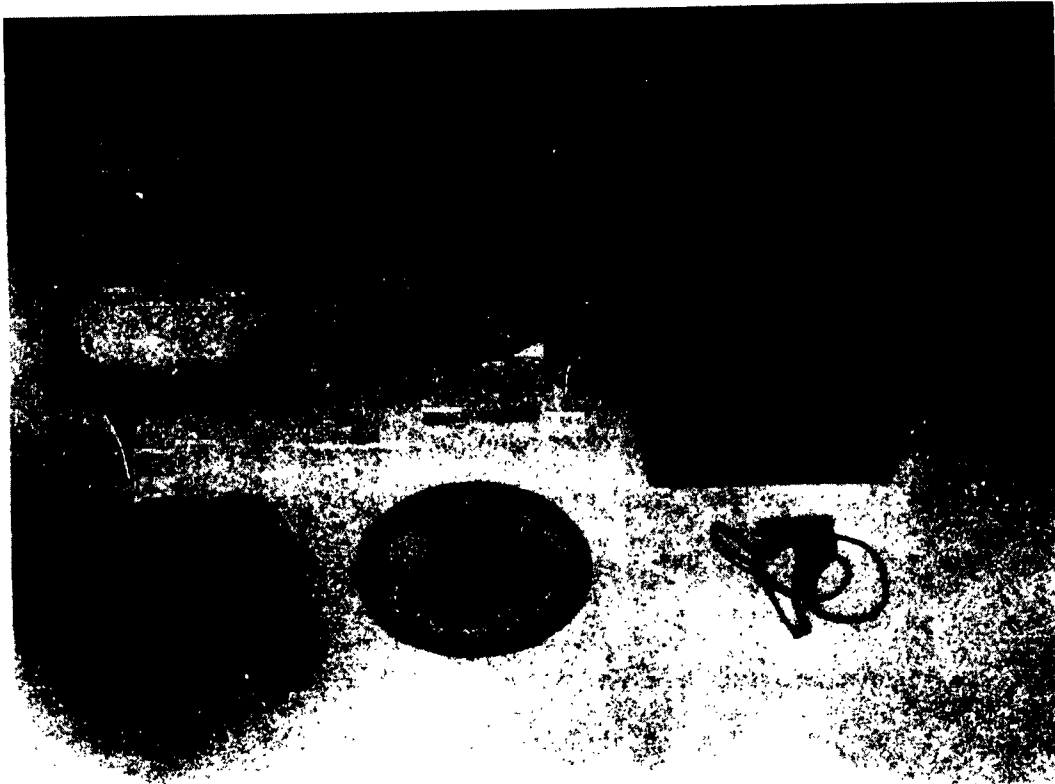
19

Figure 4 Altimeter Modification Parts

occurs above the visible spectrum at 8,300 angstroms, this presented
no problem. When lights are located around the circumference of the
instrument it is difficult to focus light directly upon detectors near
the center. Sufficient clearance is available to tilt the cells up to
15 degrees for better directivity if desired, but allowances must be
made in the encoding disc design. Other optical focusing techniques
such as reflectors or the use of fiber optics are possible. The ultimate
in an electromagnetic light source would undoubtedly be to use gallium
arsenide diodes (Ref. 3) located inside the case. This scheme was
partially tested by placing a gallium arsenide cell one quarter of an
inch in front of the altimeter face directly opposite a detector cell.
Although the transmission efficiency was quite low an output of two
microamps into a 2200 ohm load was obtained.

To complete the encoding altimeter it was only necessary to find a
method of routing the solar cell lead wires to the outside of the case.
Small grooves were cut inside the case edge and the wires routed behind
the retaining rings (Items 2 and 7, Fig. 2) to the rear of the case.
At the rear of the case, holes were drilled, terminal pins installed,
and the case was sealed with Epoxy Patch.

To review the altimeter modification process refer to Figure 2.
The interior gears at Item 6 were changed, Item 16 was removed, Item 17
was removed and replaced by the detector mounting plate, hand indicator
22 was discarded, hand 23 was replaced by the encoding disc, hand 24
was replaced with a plastic pointer, Item 20 was removed, and the dial
numbers were painted on the back of the altimeter glass face, Item 26.

21

A calibration of the converted altimeter was made using the E-1, Differential and Absolute Pressure Manometer. The calibration table and a picture of the manometer are given in Appendix C. hysteresis and friction errors were within the limits specified in Reference 1. Climatic tests were not conducted. Smith law correction (Ref. 1, Sec. 3.9) of static position defect error was not considered relevant for the altitudes and types of aircraft under consideration. Estimated cost of the altimeter conversion was $50 (Appendix D), well below the set goal of $500.

A switching amplifier, capable of making the altimeter output compatible with the logic circuitry was necessary before consideration of the logic circuit. This amplifier, shown in Figure 5, supplied zero volts to the output when the solar cell was illuminated. Otherwise, the output was a negative 10 volts. Two stages were used for temperature stabilization and better control of sensitivity. The potentiometer adjusted the sensitivity of each cell. The input impedance of the transistor gave a good maximum power transfer match for the solar cell. With the potentiometer set at mid-range and using a standard incandescent light source the energy required to produce zero volts at the amplifier output was 11 foot-candles.* Under the above conditions the output current from the solar cell to the amplifier is 9.6 microamps and the short circuit current was within 0.2 microamps of this value. The power density required at the best response wave length (8300 $\mathring{A}$) was calculated. Assuming a conversion of 14 per cent and one electron per photon the power density necessary at the solar cell was 11.4×10^{-4} watts/cm^2.

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* This figure has only relative merit, since the peak response of the solar cell lies above the visible spectrum. However, the incandescent lamp does have an output spectrum similiar to the response spectrum of the cell and was the only standard source readily available.
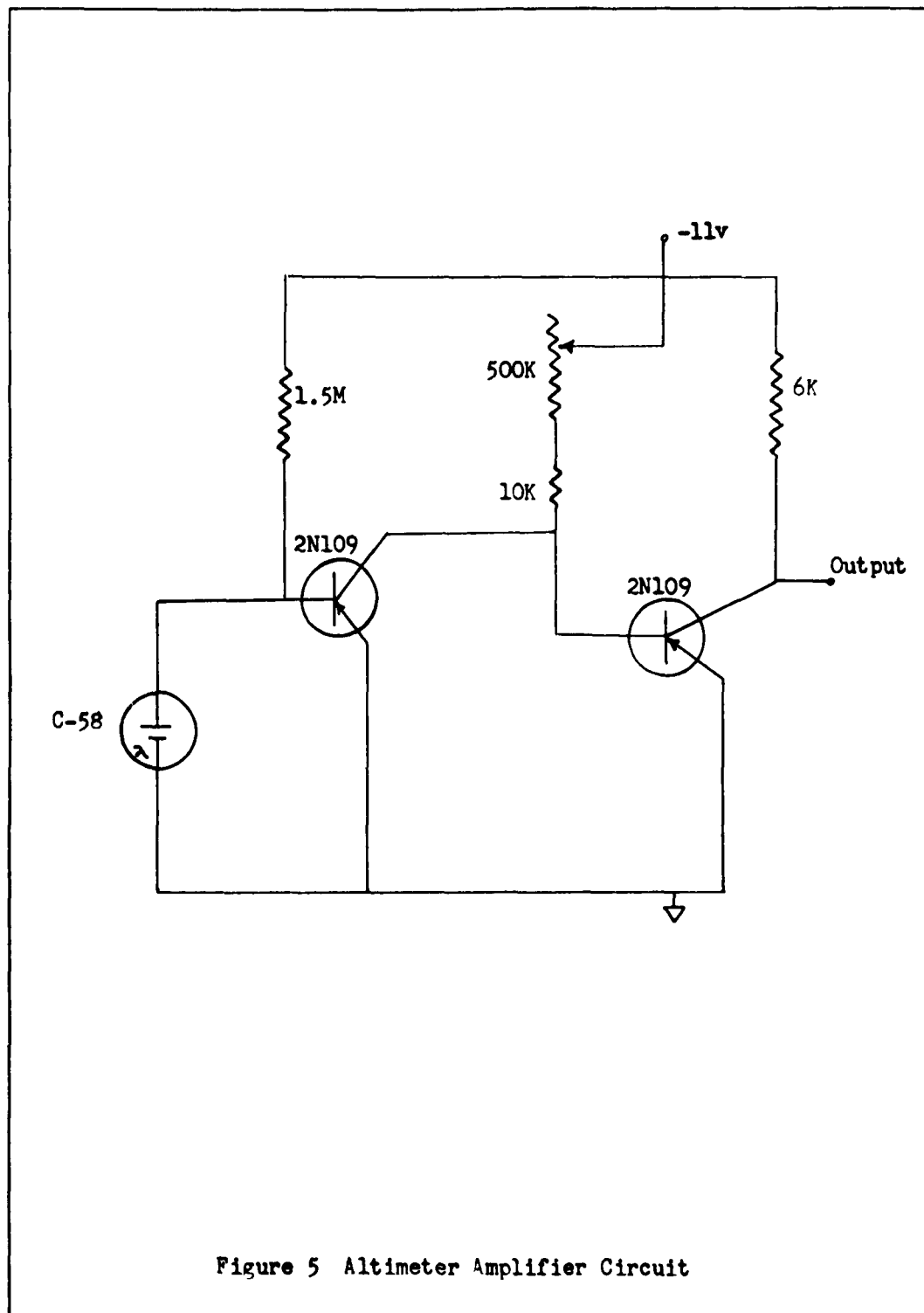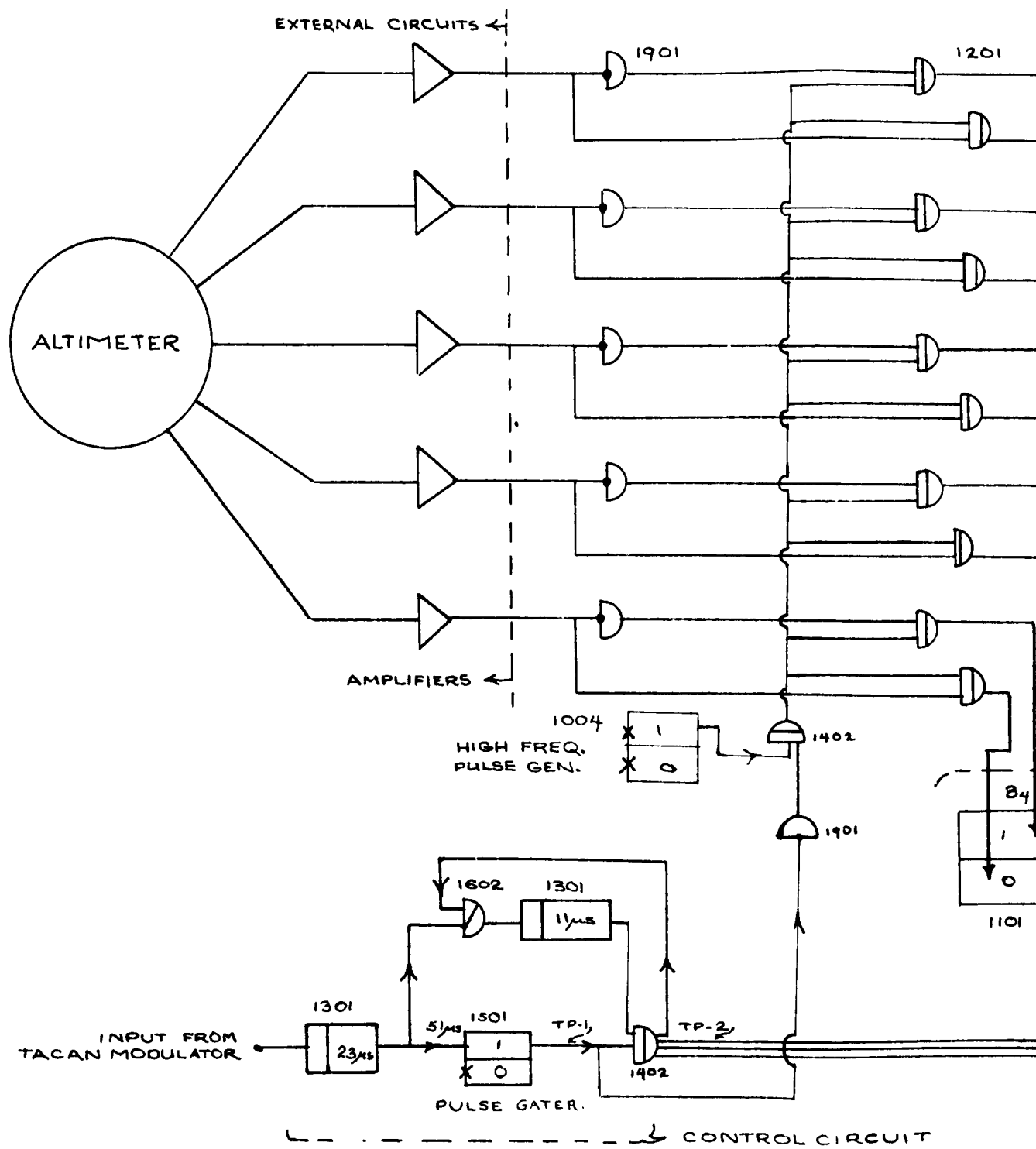
Figure 5 Altimeter Amplifier Circuit
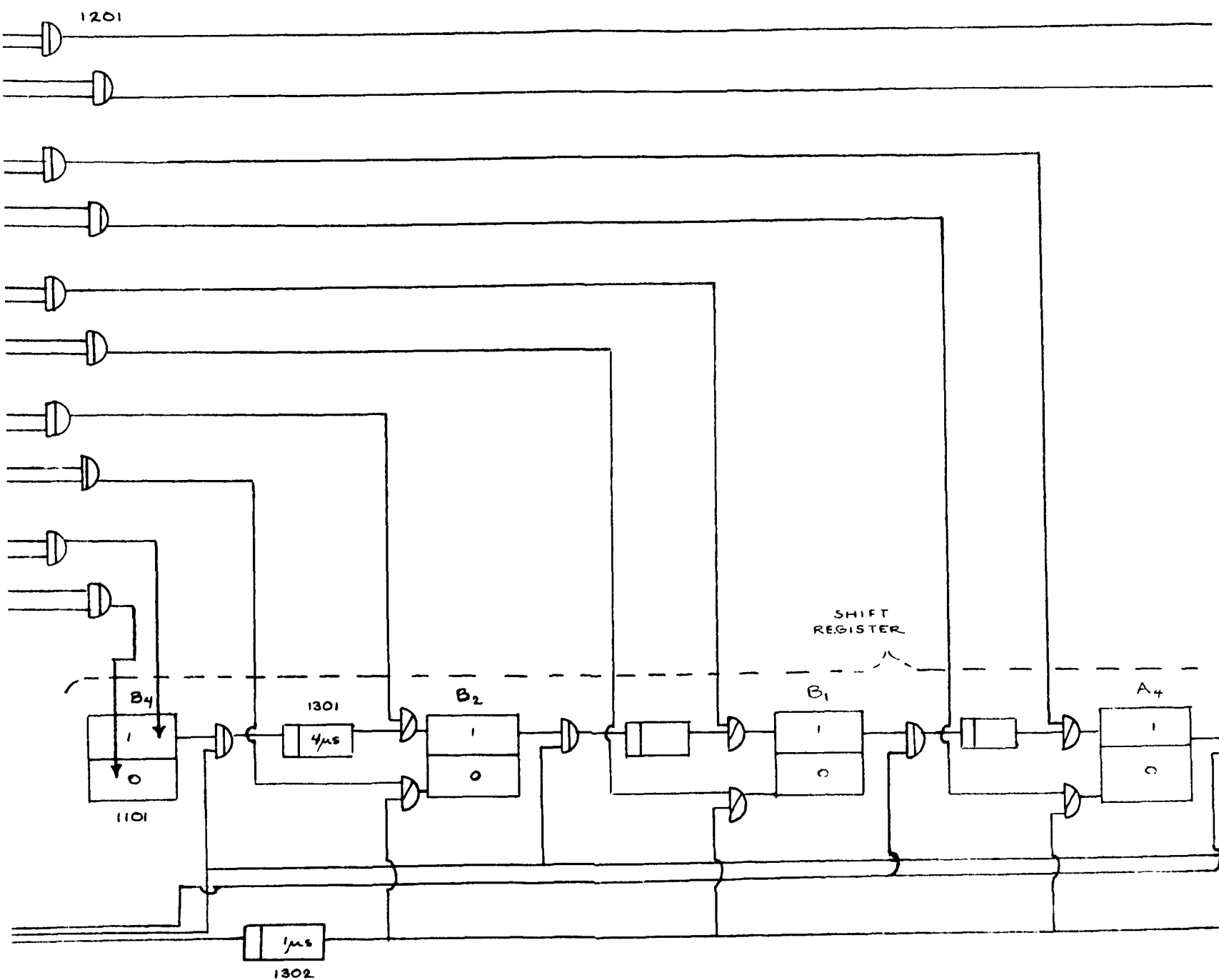
V. Logic Circuit

The logic circuit used to store the binary code discussed in Chapter 3 is shown in Figure 6. The unitized logic equipment was made by the Burroughs Corporation in 1955 and is shown in Figure 7. Naturally, this circuitry would have to be transistorized for an airborne installation. The logic circuit used is by no means unique, but the author feels it to be the best one consistent with the logic equipment immediately available. A brief description of the characteristics of the individual logic units was abstracted from Reference 2 and included in Appendix E.

For the Burroughs Equipment zero volts is used for the binary "one" state and a negative voltage (-10 to -23 volts) for the "zero" state. Of course the two states could have any names and it wouldn't matter, but having zero volts for the "one" state does occasionally become confusing when checking the circuitry.

First consider the portion of the circuit (Fig. 6) which sets the state of the shift register. The solar cells inside the altimeter are connected directly to the switching amplifier discussed in Chapter 3. An amplifier output is zero volts if light falls upon its associated solar cell, otherwise the output is minus 10 volts. The output of each amplifier is connected to two coincidence ("and") gates; one directly and the other through an inverter. A fairly high frequency (750 kc) astable multivibrator is also fed to the "and" gates and, with coincidence (zero volts) from the amplifier or inverter, sets the shift register storage unit to the appropriate state. This portion of the circuit works quite well as long as the rate of TACAN interrogation and the rate of change of the altimeter is small compared to the frequency

24

1

EXTERNAL CIRCUITS

1901

1201

ALTIMETER

AMPLIFIERS

1004

HIGH FREQ.
PULSE GEN.

X	1
X	0

1402

1901

B4

1
0

1101

1602

1301

1 μs

INPUT FROM
TACAN MODULATOR

1301

23 μs

5 μs

1501

1
X	0

TP-1

1402

TP-2

PULSE GATER.

CONTROL CIRCUIT

2

1201

SHIFT
REGISTER

B4

1301

4µs

B2

1101

B1

A4

1µs

1302

:UIT

DIGITAL LOGIC
CODE

AND

INVERTER
(NOT)

BISTABLE
MULTIVIBRATOR
(FLIP FLOP)

MONOSTABLE
MULTIVIBRATOR
(UNI)

ASTABLE
MULTIVIBRATOR

DELAY

OR

A_4

A_2

NEGATIVE
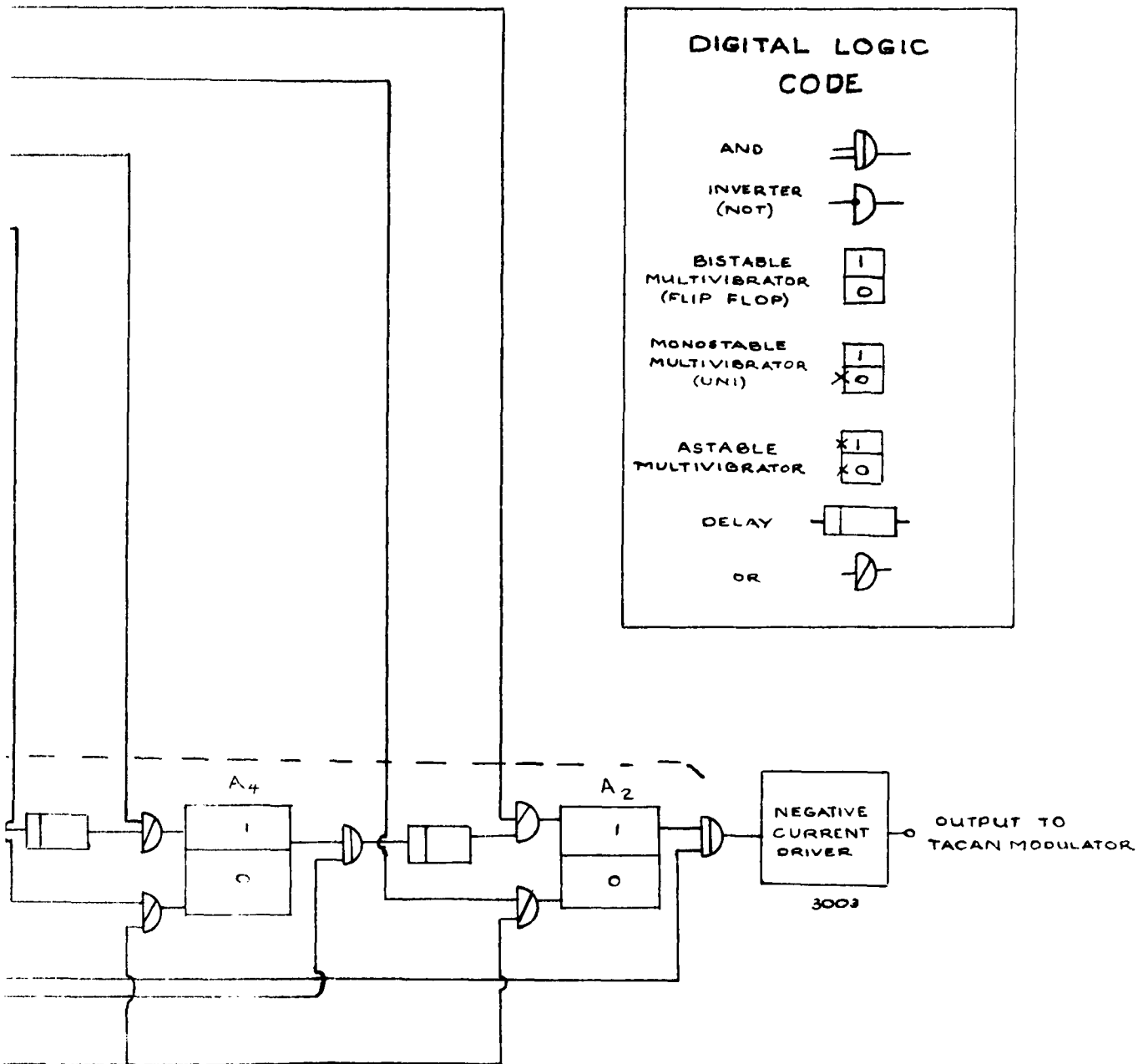CURRENT
DRIVER

3003

OUTPUT TO
TACAN MODULATOR

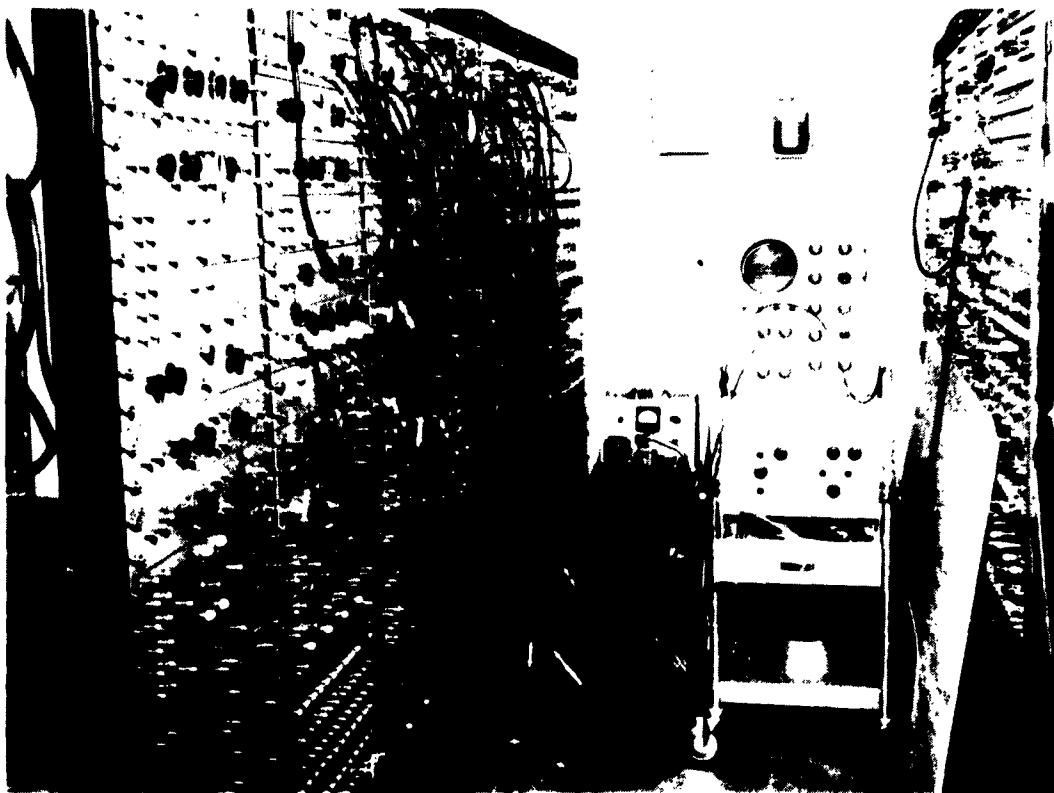FIGURE 6   DIGITAL LOGIC CIRCUIT DIAGRAM

Figure 7 Digital Logic Equipment

of the astable multivibrator and eliminates the need for a complex sequence of circuits (e.g., amplifier, Schmitt trigger, differentiation, and rectification).

Now consider the control portion of the circuit which generates the shifting pulses. A pulse from the TACAN modulator (discussed in Chapter 6) signals the logic control circuit that the modulator is about to generate two pulses for interrogation of the ground-beacon. Twenty-three microseconds later the control circuit generates five shift pulses with a period of approximately 11 microseconds. This is accomplished by the feedback network shown—the gating monostable multivibrator allows sufficient time for only five pulse outputs to the shift register. The gating multivibrator also turns off the high frequency pulse generator so that the shift register flip flops will not be "set" by the altimeter during the shift out period (approximately 51 microseconds).

The shifting of the register is accomplished serially in a standard manner which uses the least number of logic elements. For example, the first shifting pulse shifts flip flop "A_2" into the output and all others into storage delays between flip flops. Shortly thereafter the same pulse sets all flip flops except "B_4" to the "zero" state to await the output of the delay element to its left. The process is repeated five times until all the binary information has been shifted to the output of the register.

The logic control circuit may be excited directly from the TACAN modulator. However, a pulse reshaper and power amplifier is required at the output of the shift register. The bandwidth of the TACAN circuitry makes the latter statement an absolute "must" and, as will be shown later,

27

the power required for input to the TACAN is quite large.

Table 1 shows the binary "bits" associated with 500 ft. incremented altitude. The encoded "bits" leave the shift register in the following order: A_2, A_4, B_1, B_2, B_4. Figure 8 shows the altimeter with corresponding waveforms of the logic circuit output. The altimeter photos are somewhat fictitious in that they were taken in the studio. This is evident from the disappearance of the Kollsman window. Figure 9 (a) shows the logic circuit output at 9500 feet with the associated shift pulses (Fig. 6, TP-2), and Figure 9 (b) shows a transition waveform taken at 7300 feet (notice that pulse "B_4" has just come on). The output pulses are actually negative and inverted at the oscilliscope. The pulse duration and rise time may be varied at the output driver stage.

A rough estimate was made to determine the approximate price of a transistorized version of the logic circuit. This estimate amounted to $358 using the following unit prices: thirty dollars for the output power stage, ten dollars per transistor stage, five dollars for each fixed parameter delay network of short duration, and three dollars per "and" and "or" gate.

Table 1

Binary Encoded Altitude

Altitude (ft.)	Gray Code	Altitude (ft.)	Gray Code
-500	B_4	7500	$A_2 A_4$ B_4
0	$B_2 B_4$	8000	$A_2 A_4$ $B_2 B_4$
500	B_2	8500	$A_2 A_4$ B_2
1000	$B_1 B_2$	9000	$A_2 A_4 B_1 B_2$
1500	$B_1 B_2 B_4$	9500	$A_2 A_4 B_1 B_2 B_4$
2000	B_1 B_4	10000	$A_2 A_4 B_1$ B_4
2500	B_1	10500	$A_2 A_4 B_1$
3000	$A_4 B_1$	11000	A_2 B_1
3500	$A_4 B_1$ B_4	11500	A_2 B_1 B_4
4000	$A_4 B_1 B_2 B_4$	12000	A_2 $B_1 B_2 B_4$
4500	$A_4 B_1 B_2$	12500	A_2 $B_1 B_2$
5000	A_4 B_2	13000	A_2 B_2
5500	A_4 $B_2 B_4$	13500	A_2 $B_2 B_4$
6000	A_4 B_4	14000	A_2 B_4
6500	A_4	14500	A_2
7000	$A_2 A_4$		
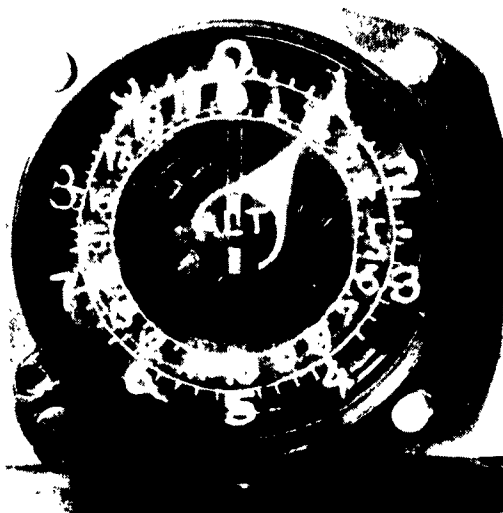
2000 ft
altimeter
reading
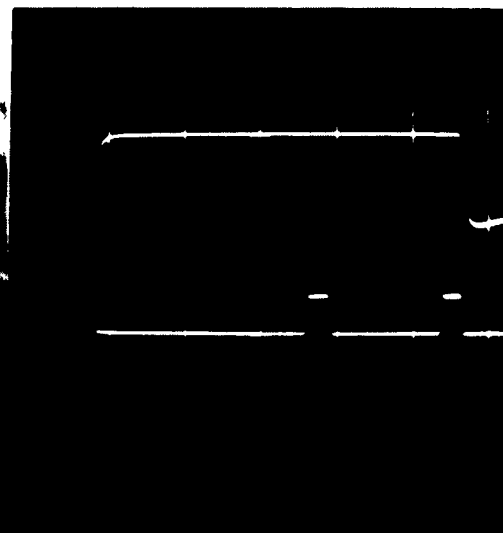
Top scan; control gate (TP-1)
Lower scan; 2000 ft output
(B_1, B_4)

(20 v/cm; 10 microsec./cm)

8500 ft
altimeter
reading
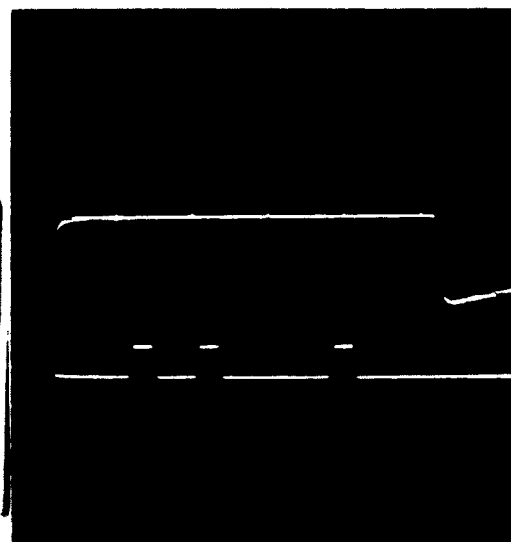
Top scan; control gate (TP-1)
Lower scan; 8500 ft output
(A_2, A_4, B_2)

Figure 8 Altimeter and Corresponding Waveforms
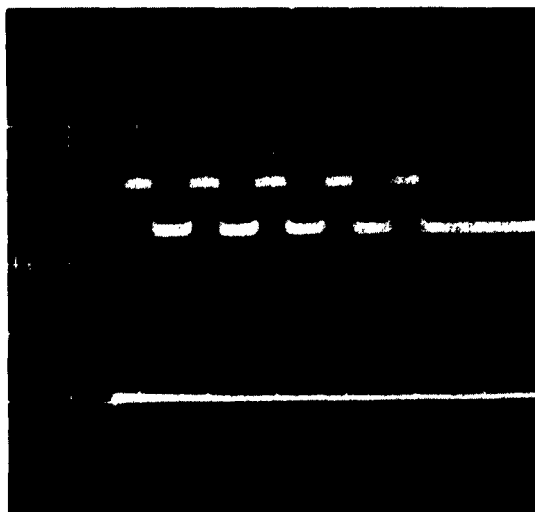
(a) Top scan, output at 9500 ft $(A_2A_4B_1B_2B_4)$
Bottom scan, shift pulses (TP-2)

20 v/cm, 10 microsec./cm

(b) Top scan, control gate (TP-1)
Bottom scan, transition to 7500 ft
(A_2A_4,B_4)
20 v/cm, 10 microsec./cm

Figure 9 Logic Circuit Waveforms

VI. TACAN

Before presenting the required changes in the Tactical Air Navigation system which will permit transmission of altitude information to the ground it is necessary to discuss TACAN in general. Readers familiar with TACAN will find this chapter rudimentary.

TACAN is a short-range aircraft navigation system which supplies continuous, accurate, slant-range bearing information. The navigational and approach information is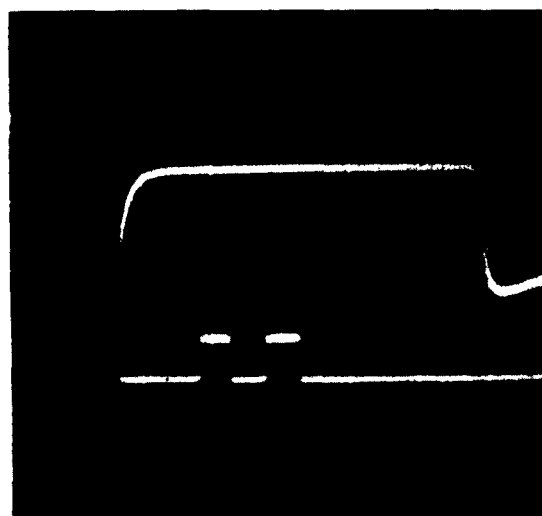 presented visually in the cockpit (Fig. 10). The normal limitations in low frequency navigational aids such as static interference, split or bent beams, and a limited number of navigational courses have been eliminated in TACAN. Distance Measuring Equipment (DME), which is an integral part of TACAN, furnishes slant-range distance information continuously from the ground facility.

TACAN operates in the UHF (1000 megacycle) band. The TACAN system has a total of 126 two way channels. Air-to-ground frequencies (required only for the distance function) of these channels are in the 1025-1150 mc range; associated ground-to-air frequencies lie on either side of this range and are in the 962-1024 mc and 1151-1213 mc ranges. Channels are clear frequency and spaced at 1 mc intervals, they do not depend on pulse coding. The complete system block diagram is shown in Figure 11.

The azimuth and distance information is provided by a multichannel airborne receiver-transmitter (AN/ARN 21, Ref. 10) and presented to the pilot in the aircraft. The maximum range at which this information may be received is approximately 200 nautical miles. It should be noted here that civil aircraft do not presently use TACAN as such, but normally
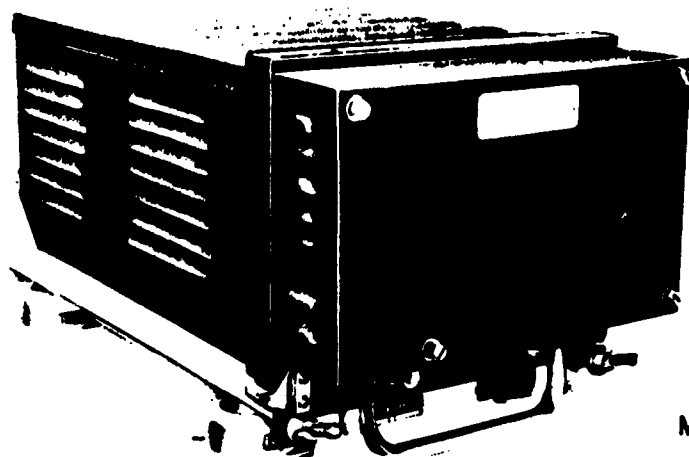
**RADIO
RECEIVER-TRANSMITTER
RT-220( )/ARN-21**

**MOUNTING
MT-928/ARN-21**
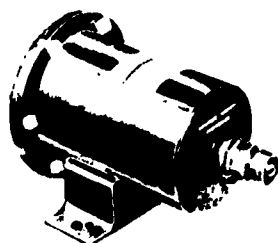
**PHASE DETECTING NETWORK
CV-279/ARN**

**AZIMUTH INDICATOR
ID-307/ARN**

**RANGE INDICATOR
ID-310/ARN**

**RADIO SET CONTROL
C-1763/ARN-21A**
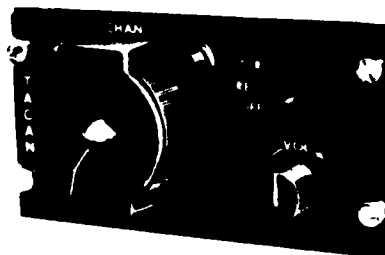
Figure 10   Radio Set AN/ARN-21B

33
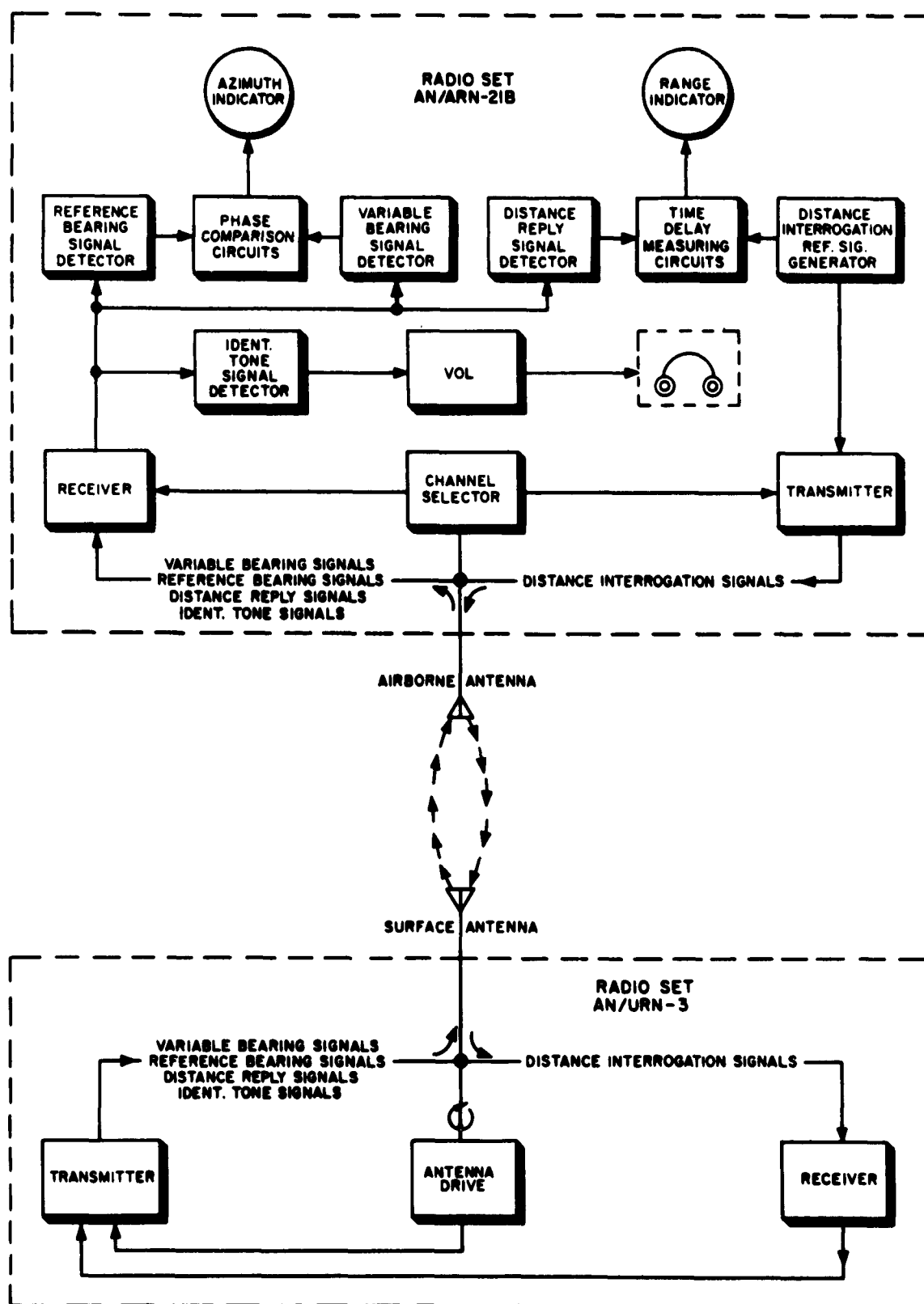
Figure 11 Over-all System Simplified Block Diagram

34

use just the distance-measuring portion and obtain their azimuth information from Very High Frequency Omni Range (VOR) facilities.

The TACAN ground equipment consists of a receiver-transmitter combination and a rotating antenna for the transmission of bearing and distance information. The ground station identifies itself through International Morse Code each 30 seconds.

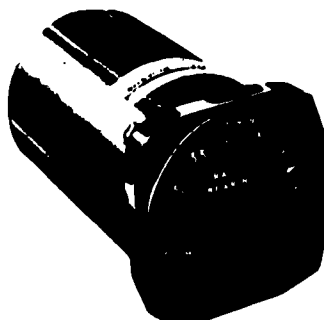The two basic functions of TACAN will now be described. The azimuth or bearing measurement portion of the system will be considered first, although quite briefly, since it has little relevance to the thesis problem. The distance measuring portion will be described second and in considerable more detail.

The ground-beacon transmitter operates at a constant-duty-cycle of about 2700 pulses per second of constant amplitude at all times. These pulses are made up of a combination of distance-measurement reply pulses, filler pulses, station identification pulses, and phase reference pulses. For bearing-phase, amplitude modulation is accomplished by mechanically rotating two parasitic antennas around a central element producing a rotating cardioid pattern. The depth of this modulation is small so that the pulse information is not lost. Two parasitic antennas are used to increase bearing accuracy. The parasitic antennas rotate together from the same drive motor at 15 revolutions per second. The inner rotating element is one wire in a fiber glass drum and produces coarse bearing information (40° sectors) while the outer rotating drum has nine wire elements producing a 135 cycle per second signal which is used as "fine phase" information by the aircraft receiver to determine azimuth within each 40° sector by plus or minus one degree. The advantages of the TACAN fine bearing transmission over the older Very High Frequency Omni Range

(VOR) signals are the increased bearing accuracy and less interference due to propagational reflections (Ref. 6).

The distance measuring function of TACAN is accomplished by measuring the round-trip travel time of radio pulse signals. The aircraft interrogates the ground beacon with very narrow but widely spaced pulses. The ground equipment receives these interrogations and, after a 50 microsecond delay, triggers the associated transmitter on a different channel. Timing circuits in the aircraft measure the time between interrogation and reply and operate a distance meter in the cockpit. The range at which aircraft can receive distance information depends upon the aircraft's altitude, but at most is about 200 nautical miles.

In order that more than one aircraft may use one ground-station it is necessary for the interrogation pulses from each aircraft to randomly vary or "jitter." This is accomplished in the aircraft transmitter modulator by an unstabilized multivibrator. An automatic stroboscopic search process in the aircraft locates the correct reply pulses by finding repeated reply pulses which have a fixed or slowly varying time delay in relation to the transmitted interrogations. The strobe scans a sliding range gate and tests successive positions until finding some particular time delay interval whose pulses are in synchronism with those transmitted. The interrogation pulse rate is higher (150 pulses per second) in the "search" condition than when "locked-on" (30 pulses per second). A crystal-controlled 4046 cps oscillator is used as the time reference. The time delay between interrogations and reply is measured in terms of the number of cycles or fractions of cycles of this signal. To establish an accurate zero reference the same signal is used to trigger

the nonstabilized multivibrator in the transmitter modulator.

The pulses discussed above are actually twin pulses with a spacing of twelve microseconds. Both ground and airborne receivers have decoders that pick only pulse pairs of the correct spacing. This makes the system more interference free from false signals and noise.

The capacity of the distance measuring portion of TACAN is approximately one hundred aircraft. This is based on the assumption that 5 per cent of the interrogating aircraft will be in the "search" (150 pulses per second) condition and the other 95 per cent will be in the "track" (30 pulses per second), thus using up the entire ground beacon transmitter capacity. Note also that the duty cycle of the airborne transmitter is extremely low (around 2 per cent) and that a great deal of frequency space is open for the addition of other information. This was a basic premise of the designers of TACAN (Ref. 6:12), that is, to multiplex additional navigation functions on TACAN channels.

VII. TACAN Modifications

The pulse code multiplexing of altitude information with the DME interrogation signals requires only consideration of the modulator circuit. The relationship of the modulator with respect to the complete radio frequency circuitry is shown in Figure 12. A block diagram of the modulator and the related range circuits are shown in Figure 13.

Before discussing any modifications it is useful to determine how the modulator operates. Refer to foldout Figure 14. Starting at the left, the pulse repetition frequency (PRF) astable multivibrator produces pulses which, when coincident with 4046 cps time reference pulses from the range gate, "fire" the first pulse generator tube V702. The PRF multivibrator is not stabilized, i.e. the discharging path though C702 is long and therefore any variation in circuit parameters such as temperature, noise, etc., will change the tube operating point and vary the PRF. This is the phenomenon that allows each receiver to distinguish its own reply pulses from those to other aircraft. The gate pulses vary in the vicinity of 150 pps in "search" and in the vicinity of 30 pps in "track." These two rates are controlled by the stroboscopic range gate of the receiver. The bottom of resistor R706 is "grounded" through a relay (not shown) when the range gate is in the search condition, but "open" when the range gate receives the correct reply pulses and stops its searching process.

The first pulse generator, on coincidence of a 4046 cps pulse at the screen and a PRF multivibrator pulse at the grid, creates the first transmitted pulse through network C705 and L701. This pulse

38
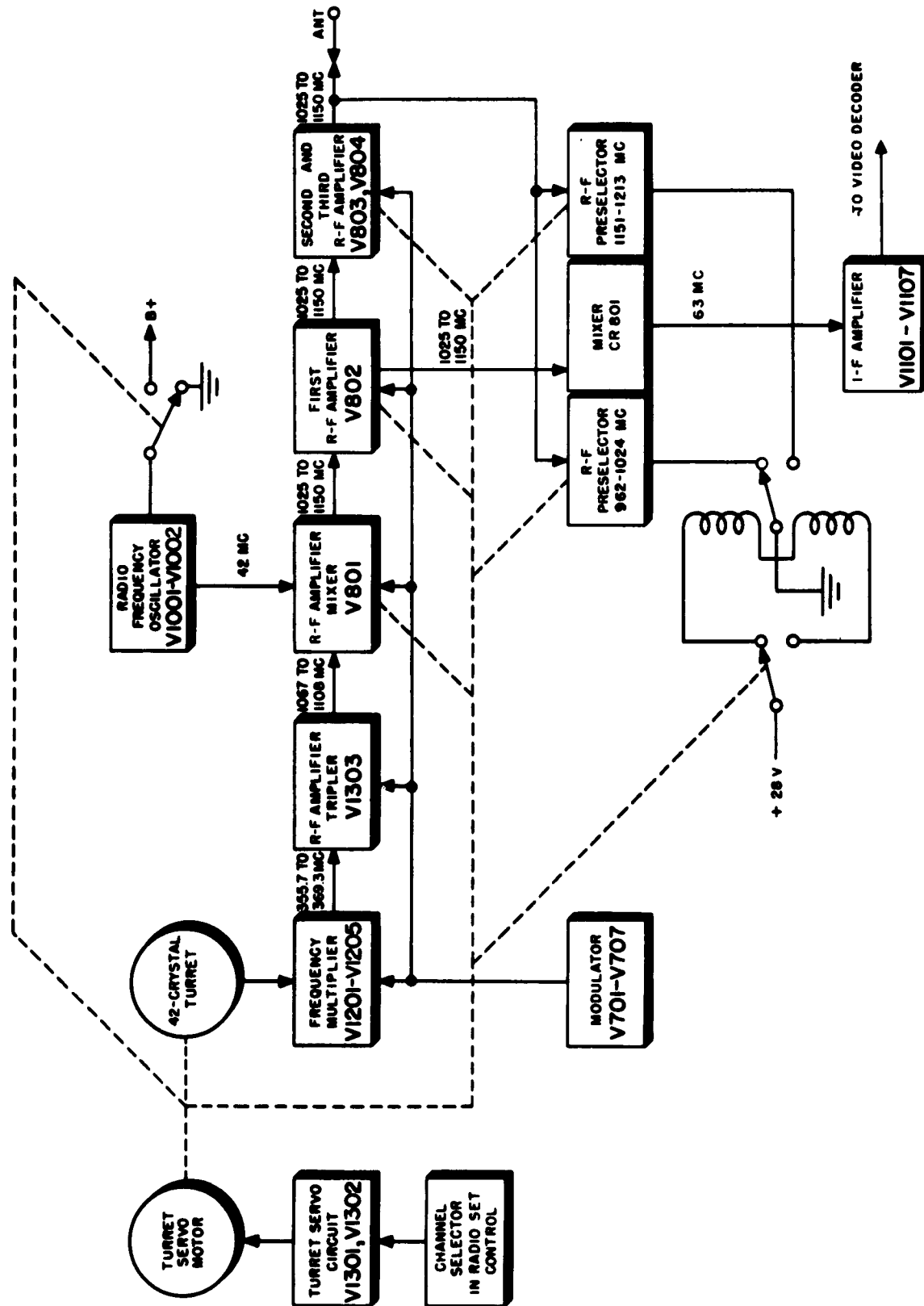
Figure 12 RF System Block Diagram

39
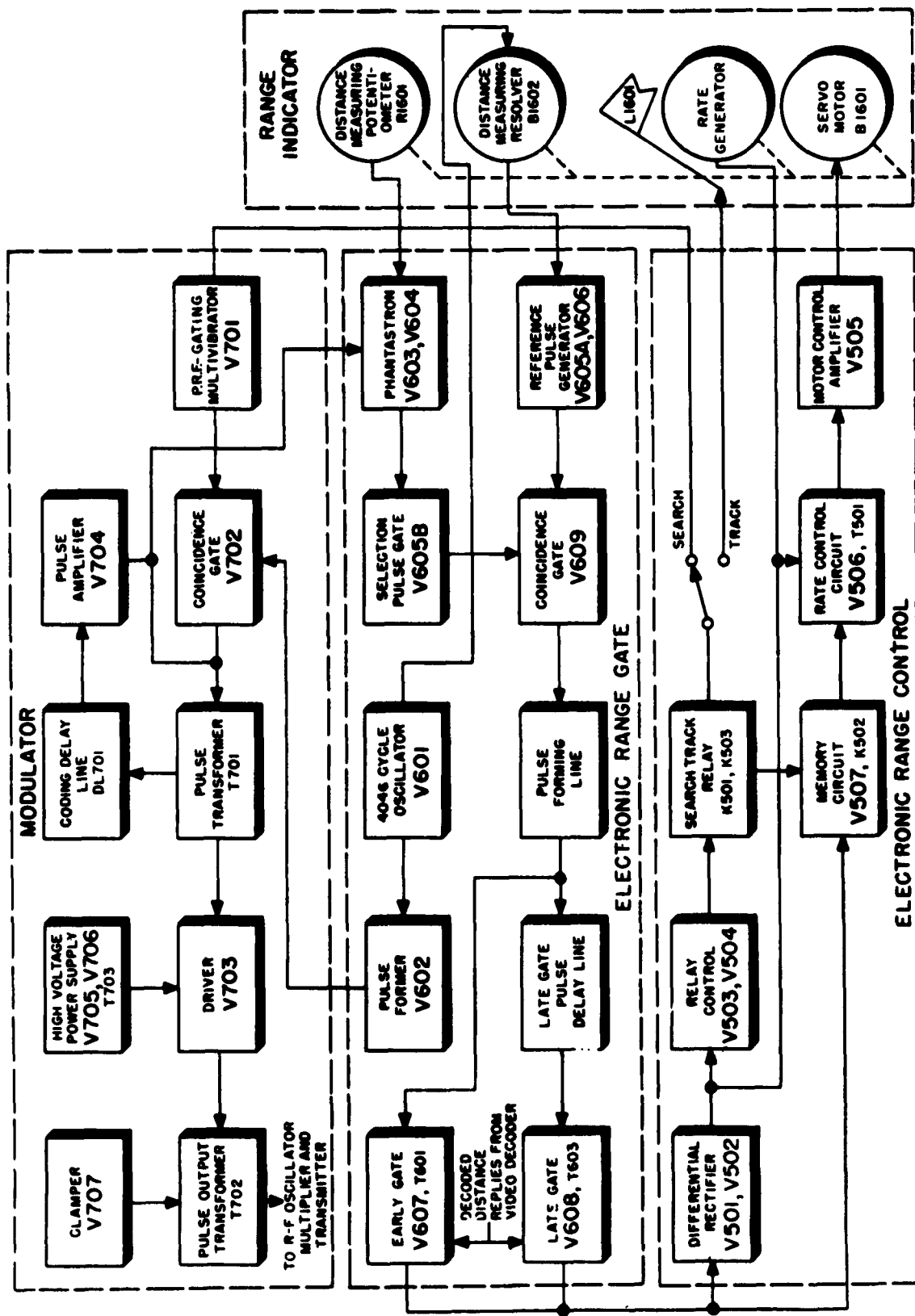
Figure 13 Modulator and Range Circuits, Simplified Block Diagram

continues through transformer T701 and the power amplifier to drive
succeeding stages of the transmitter (frequency multiplier, tripler
amplifier, and RF oscillator). This same pulse returns through the 12
microsecond delay network DL701 and "fires" thyratron V704 to produce
the second pulse of the twin pulse pair. A third pulse is not produced
because V704 does not return to its static state for considerably more
than 12 microseconds.

The modifications to the modulator necessary for the inclusion of
altitude information are shown in Figure 15 before and after transformer
T701. The output of the logic circuit is introduced at the primary of
T701 (pin 2) and passes through the transmitter in the same manner as
the interrogation pulses. To keep the logic circuit inputs from exciting
the second pulse generator it is necessary to remove the wire to the
delay line from the secondary of T701 (pin 3) and operate the second
pulse generator from the primary side. A diode is used to isolate both
pulse generators from the logic input. The second pulse of the twin pulse
interrogation is generated essentially as before by adding an amplifier
to the circuitry. This circuit shown in the lower part of Figure 15
inverts and amplifies the first interrogation pulse from the primary
side of T701 and returns it to the grid of the second pulse generator
through the delay line. A pulse transformer would have served better
than the amplifier but was not readily available.

No modifications are required to run the logic circuit as a
"suppression pulse" is provided from the network connected to the cathode
of the first pulse generator. This "suppression pulse" from terminal 5

41

P701

+120 V — 10

4046 CPS
PULSE
TRIGGER FROM — 11
RANGE GATE

PRF CONTROL — 1

-180 V — 3

PULSE TO
FRONT PANEL — 5
(J112)

+380 V — 8

SUPPRESSION
+35 VOLT PULSE
TO DISTANCE — 2
MEASURING
POTENTIOMETER

G4

R702 27K
R701 27K

V701 6021
PRF MULTIVIBRATOR
A B
R704 12K

R703 1K
R705 1.2 MEG

R732 10K   R731 560K
R706 1.2 MEG

C717 0.1 UF

R736 56K   CR702 1N69

C701 0.068 UF   R710 470K   R711 22K

C702 5600

C718 390   R708 330K

R737 2200

R709 680K   C719 5   C715 3300

G

C703 0.1UF

R715 220K   R713 15K

R733 180   L702 4.7 UH   R714 4700

CR701 1N69

R734 1 MEG   R735 22K

R711
22K

R737
2200

G1

G2

R707
22K

C705
0.056 UF

5,7

V702
2D21W
COINCIDENCE GATE
AND PULSE GENERATOR

6

1

2

3   4

9

C715
3300

C703
0.1UF

R712
3K

G3

R716
22K

V704
2D21W
SECOND PULSE
GENERATOR

6

5,7

1

2

3   4

X

xC706
0.062 UF

R714
4700

L702
4.7 UH

CR701
1N69

+
-

2

DL701

DELAY NETWORK: $Z_0 = 3000$ OHMS

R734
1MEG

R735
22K

A

L701

B

3

2

1

T701

2

3

1

4

C707
0.047 UF

C708
0.1UF

C709
510

R721
270

R720
12

6

1

4

8

2   7

X

V703
3D21B
POWER
AMPLIFIER

G5

E711

T702

5

6

R719
10

R723
12

C710
0.22 UF

R725
220K
2W

R724
470K
2W

R717
390

C704
3300

E711

T702

7

2400VΛ TO 2ND AND 3RD RF AMPLIFIERS

5

120 VDC,1200VΛ

7

120 VDC,400V PULSE TO V1203-4-5 AND RF TRIPLER ANODE V1303

1

4

V703 3D21B POWER AMPLIFIER

6

3

2

C714 0.047 UF

R730 100 1 W

2,7,9

V707 6V3A CLAMPING DIODE

C713 0.15 UF

R728 5600 2W

6

E708

50 VDC PLUS 400V PULSE TO J1301-5

4

R727 10M 1 W

E706

5 4

X

V706 5517 HIGH VOLTAGE RECTIFIER

4

X

15

6.3 VAC

+2200V

7

E709 E710

C712 0.5 UF

13

R725 220K 2W

R726 10M 1 W

C711 0.5 UF

940 OR 670 VAC

T703

5 1

2

R724 470K 2W

E707

4 3

V705 5517 HIGH VOLTAGE RECTIFIER

HIGH ALTITUDE RELAY

6 7 2 3

K701

5 1 8 4

7

115V 320-10003 (DELAYED)

12

+28V TO ALTITUDE SWITCH S102

✱ REFERENCE DESIGNATION
C706
R721

NOTES:
1. UNLESS OTHER ARE 1/2 WATT, OHMS, AND CAP MICRO-MICROF

2. "K" INDICATES INDICATES MILI INDICATES MIC

Figure 14 Radio Modulator Schematic Diagram

2400 VΩ TO 2ND AND
3RD RF AMPLIFIERS

120 VDC, 1200 VΩ

6 — 120 VDC, 400V
PULSE TO VI203-4-5
AND RF TRIPLER
ANODE VI303

R730
100
I W

C713
0.15 UF

R728
5600
2 W

2,7,9

V707
6V3A
CLAMPING
DIODE

E708

5 4

X

4 — 50 VDC PLUS 400V
PULSE TO JI301-5

E706

V706
5517
HIGH VOLTAGE
RECTIFIER

X ← 15 — 6.3 VAC

C712
0.5 UF

C711
0.5 UF

E707

13

T703

5 1

940 OR 670 VAC

2

4 3

V705
5517
HIGH VOLTAGE
RECTIFIER

6   7   2   3

K701

5   I

8   4

7 — 115V 320-10003
(DELAYED)

12 — +28V TO
ALTITUDE
SWITCH S102
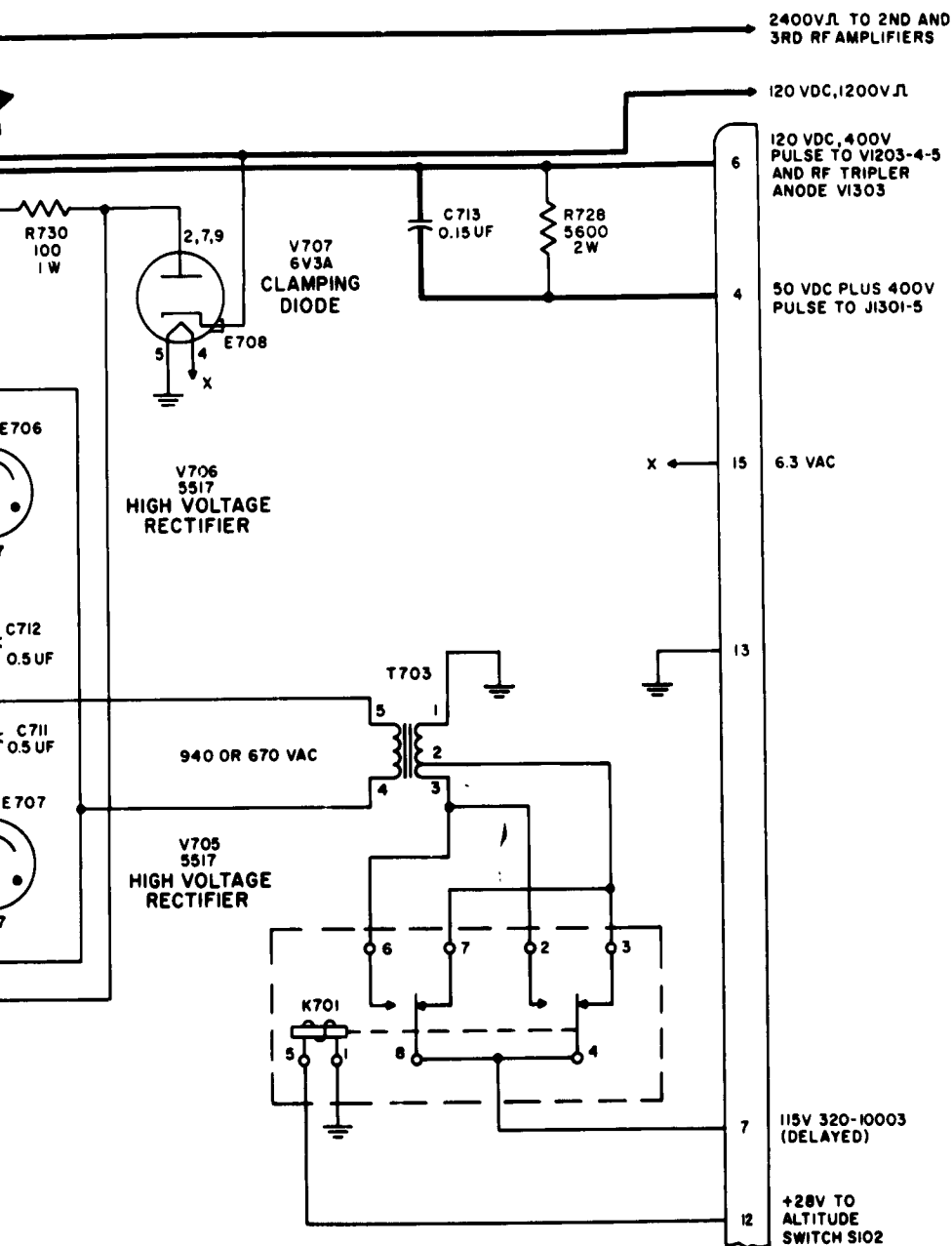
✱ REFERENCE DESIGNATION	MFR CODE	VALUE
C706	CFT	0.0062 UF
	CCT	0.0062 UF
	CKB	0.0068 UF
R721	CFT	270 Ω
	CCT	270 Ω
	CKB	160 Ω

NOTES

I UNLESS OTHERWISE INDICATED RESISTORS
ARE 1/2 WATT, RESISTANCE VALUES ARE IN
OHMS, AND CAPACITANCE VALUES ARE IN
MICRO-MICROFARADS.

2 "K" INDICATES THOUSANDS OF OHMS, "MEG"
INDICATES MILLIONS OF OHMS, AND "UF"
INDICATES MICROFARADS

Figure 14   Radio Modulator Schematic Diagram

42

Figure 15 Modifications to Modulator Circuit

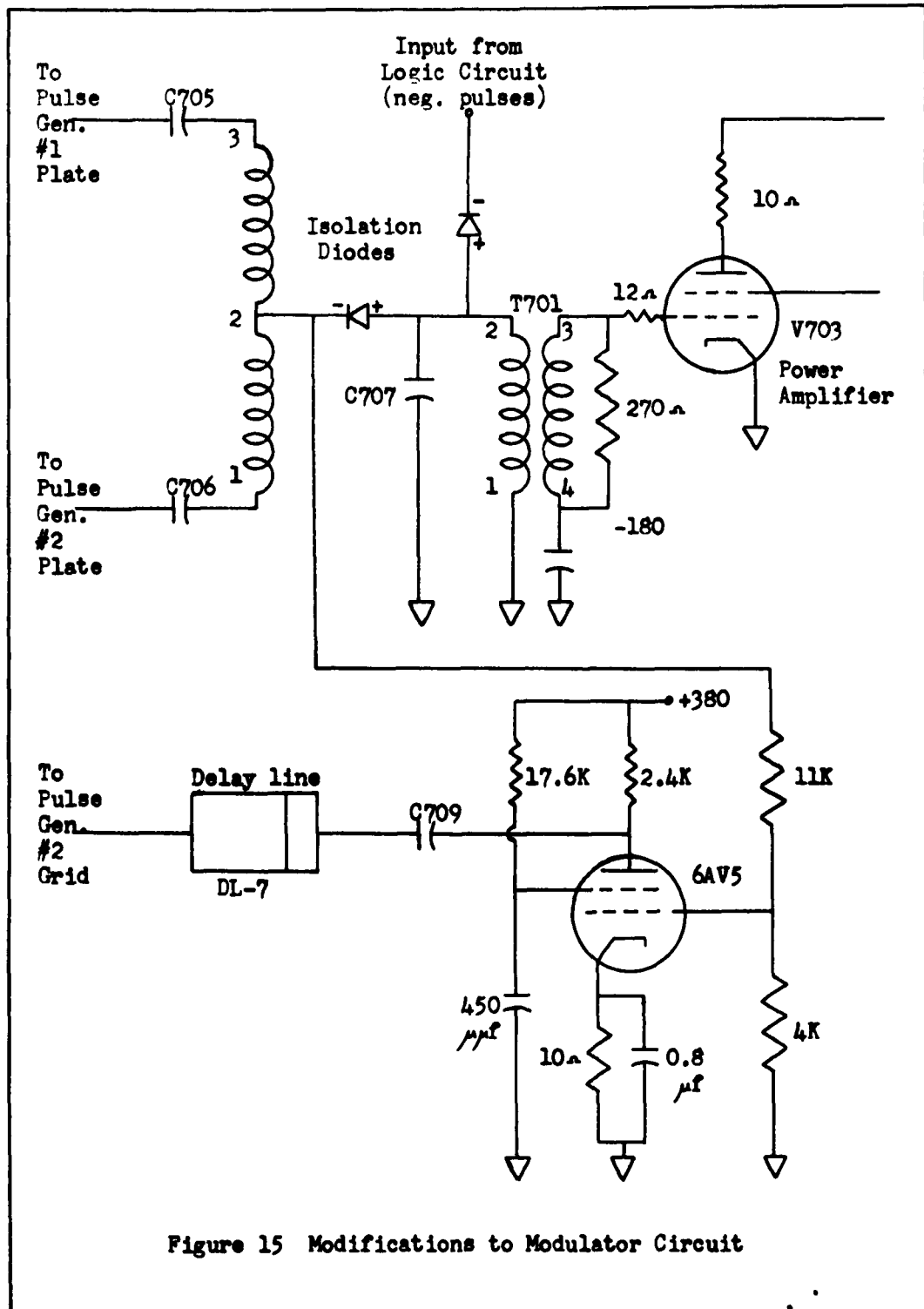on the extreme left of Figure 14 is used to cut off other aircraft equipment adversely affected by the TACAN transmitter. The pulse occurs at the beginning of the first transmitted pulse, is about 30 volts positive with a rise time of 0.5 microseconds, and is ideally suited for operation of the logic control circuit.

Modification to the modulator is now complete; a pulse is available for driving the logic circuit and the necessary changes have been made to activate the stored altitude information. Figure 16 shows the time relationships between the logic circuit exciting pulse, the TACAN interrogating pulses and the logic circuit shift pulses.

Naturally, some equipment changes would be required in the ground receiver to realize the complete system. Low altitude encoding would necessitate changing the basic 50 microsecond delay in the ground transmitter (Ref. 6:30) to 74 microseconds. Also, additional ground decoding equipment would have to be added.

TACAN test board
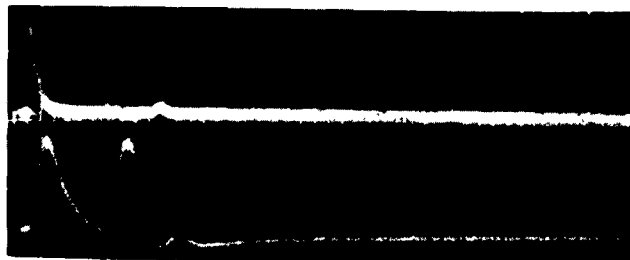
(a) Pin 5, P701, logic
driving pulse
(20 v/cm, 10 μs/cm)

Pin 3, T701, before
circuit modification
(200 v/cm, 10 μs/cm)

(b) Pin 3, T701, using
amplifier modification
and 2000 ft input from
logic circuit
(200 v/cm, 10 μs/cm)
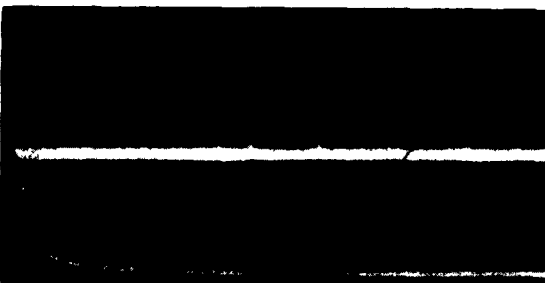
(c) Pin 3, T701, using
8500 ft input from
logic circuit
(200 v/cm, 10 μs/cm)

(d) TP-2, logic circuit shift
pulses
(20 v/cm, 10 microsec./cm)

Pin 5, P701, logic driving
pulse
(20 v/cm, 10 microsec./cm)

Figure 16   TACAN Test Board and TACAN Waveforms

VIII. Summary and Conclusions

The basic accomplishments of this project can be summarized as follows:

1. An economical altitude encoder using a standard altimeter was designed and constructed.

2. Amplifiers to enable the encoder to operate a binary circuit were built.

3. A logic system was designed and assembled.

4. A TACAN modulator was modified to permit transmission of altitude information.

It can be concluded from the study that it is possible to assemble an altitude encoder at a reasonable cost and; thus, private aircraft owners should be included in future automatic altitude reporting developments. Also, it can be concluded that the multiplexing of Air Traffic Control functions with distance measuring interrogation signals is feasible. A cost analysis would most likely prove this system to be more economical than the addition of a radar transponder to those aircraft already using DME.

IX. Recommendations for Further Study

Another related problem in Air Traffic Control is that of identification, or some way of positively determining which aircraft is sending information to the ground. To date, neither FAA nor ICAO has attempted to derive a positive identification code. For voice communications a "name" and from three to five decimal digits are used for identification (e.g., American 302, Air Force 45123). Obviously, the use of alphabetical symbols increases the binary "bits" required and a purely numeric nomenclature should be used. Even so, if 120,000 aircraft use the airspace over the United States, seventeen "bits" are required for identification and, if an attempt is made to categorize aircraft, the number of "bits" can be reduced by only two or three.

Another possible solution to this problem is not to use aircraft identification at all but supply sufficient information to the ground computer so that a "comparison" can be made automatically with the proposed flight plan and identity indirectly established. For instance, within a 200 nautical mile radius of a TACAN ground beacon, one "bit" of information can be used to establish aircraft inbound or outbound from the station, six "bits" to establish aircraft magnetic bearing (airway) within 5.6 degrees, and six "bits" to establish distance from the station to within 3.12 nautical miles. This procedure not only gives indirect identification but also aircraft position within the limits specified and could possibly be used instead of radar. All the above information "bits" are available from aircraft instruments and would make an interesting encoding problem.

Another field of study which needs consideration is that of the

air traffic control computer. FAA has done some work in this field but
because of the urgent need for altitude encoding has not been able to
devote too great an effort to the logic, programs, and speed required in
such computers.

The following list gives further projects needing study which are
directly related to this thesis:

1. A study of the TACAN ground station and the best method
   of decoding ATC information.

2. A complete analysis of the TACAN duty factor, i.e.,
   the determination of how much distance interrogation
   information is lost with the addition of each ATC infor-
   mation "bit"

3. The design and construction of an altitude encoder for
   "high" altitude using gallium arsenide diodes as an
   optical light source as outlined in Chapter 4.

4. The construction of an airborne ATC logic circuit package
   compatible with TACAN.

5. A complete study of the airborne TACAN transceiver to
   decrease its cost and increase its reliability.

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1

A_4, B_1, B_2, B_4, Pulses *

D_2, D_4, A_1, A_2 Pulses

* O or 1 in a pulse position indicates the absence or presence of a pulse respectively.

	0000	0001
0000	0	1
0001	31	30
0011	32	33
0010	63	62
0110	64	65
0111	95	94
0101	96	97
0100	127	126
1100	128	129
1101	159	158
1111	160	161
1110	191	190
1010	192	193
1011	223	222
1001	224	225
1000	255	254

REPLY PULSE ASSIGNMENT

500 FOOT INCREMENT GRAY CODE

D_2
D_4
A_1
A_2
A_4
B_1
B_2
B_4

FOR 100 FOOT INCREMENT SEE BELOW

C_1
C_2
C_4

ALTITUDE IN THOUSANDS OF FEET

500 FOOT GRAY CODE FROM ABOVE

A_1
A_2
A_4
B_1
B_2
B_4

100 FOOT INCREMENT CODE

C_1
C_2
C_4

ALTITUDE IN FEET

-1000 -500 0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500

F_1 C_1 A_1 C_2 A_2 C_4 A_4 X B_1 D_1 B_2 D_2 B_4 D_4 F
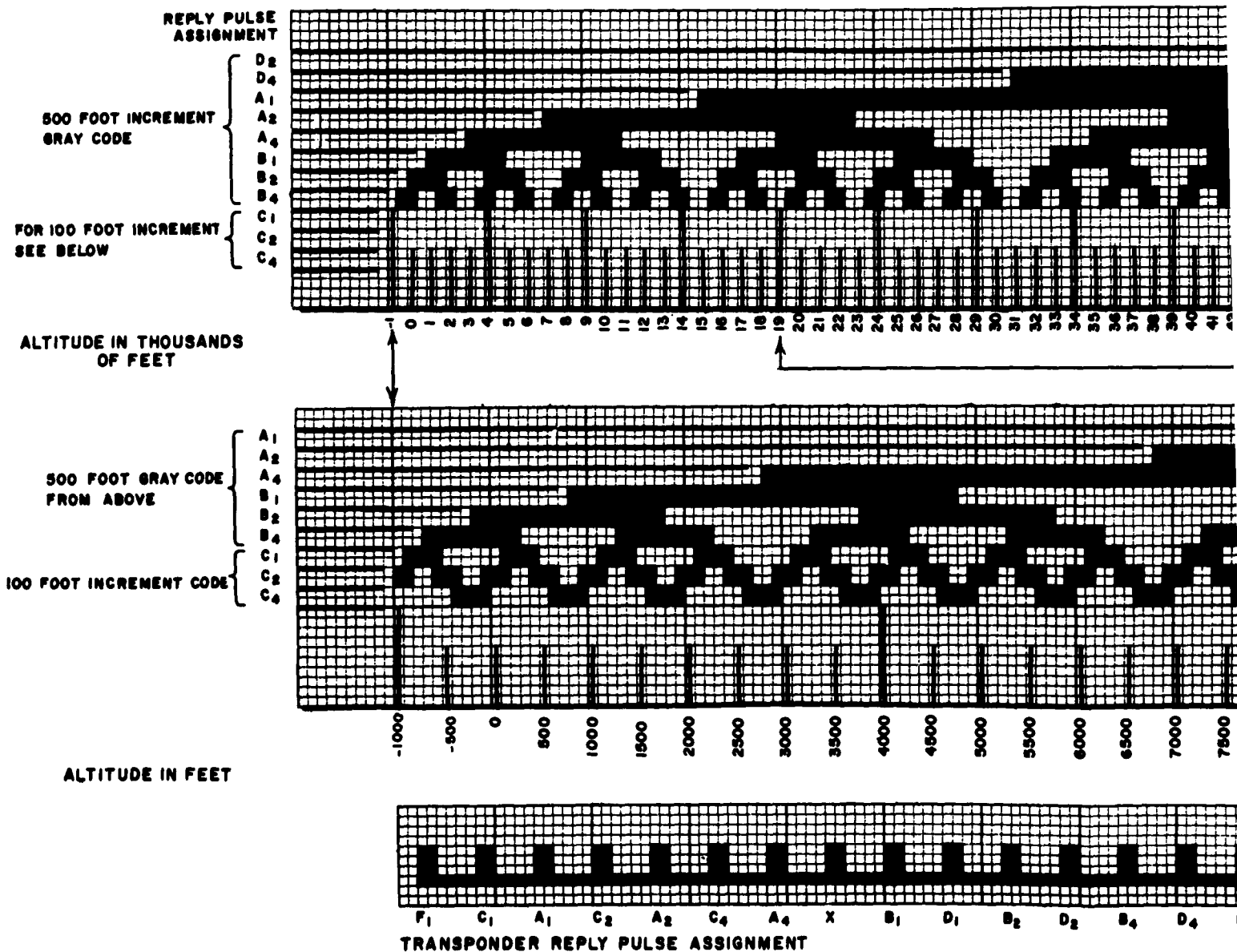
TRANSPONDER REPLY PULSE ASSIGNMENT

TABLE

UNIT DISTANCE REFLECTED BINARY CODE FOR 8 BITS

	0000	0001	0011	0010	0110	0111	0101	0100	1100	1101	1111	1110	1010	1011	1001	1000
00	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
01	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
11	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
10	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
10	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
11	95	94	93	92	91	90	89	88	87	86	85	84	83	82	81	80
01	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111
00	127	126	125	124	123	122	121	120	119	118	117	116	115	114	113	112
00	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143
01	159	158	157	156	155	154	153	152	151	150	149	148	147	146	145	144
11	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175
10	191	190	189	188	187	186	185	184	183	182	181	180	179	178	177	176
10	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207
11	223	222	221	220	219	218	217	216	215	214	213	212	211	210	209	208
01	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239
00	255	254	253	252	251	250	249	248	247	246	245	244	243	242	241	240

256 Increments (500 foot each)
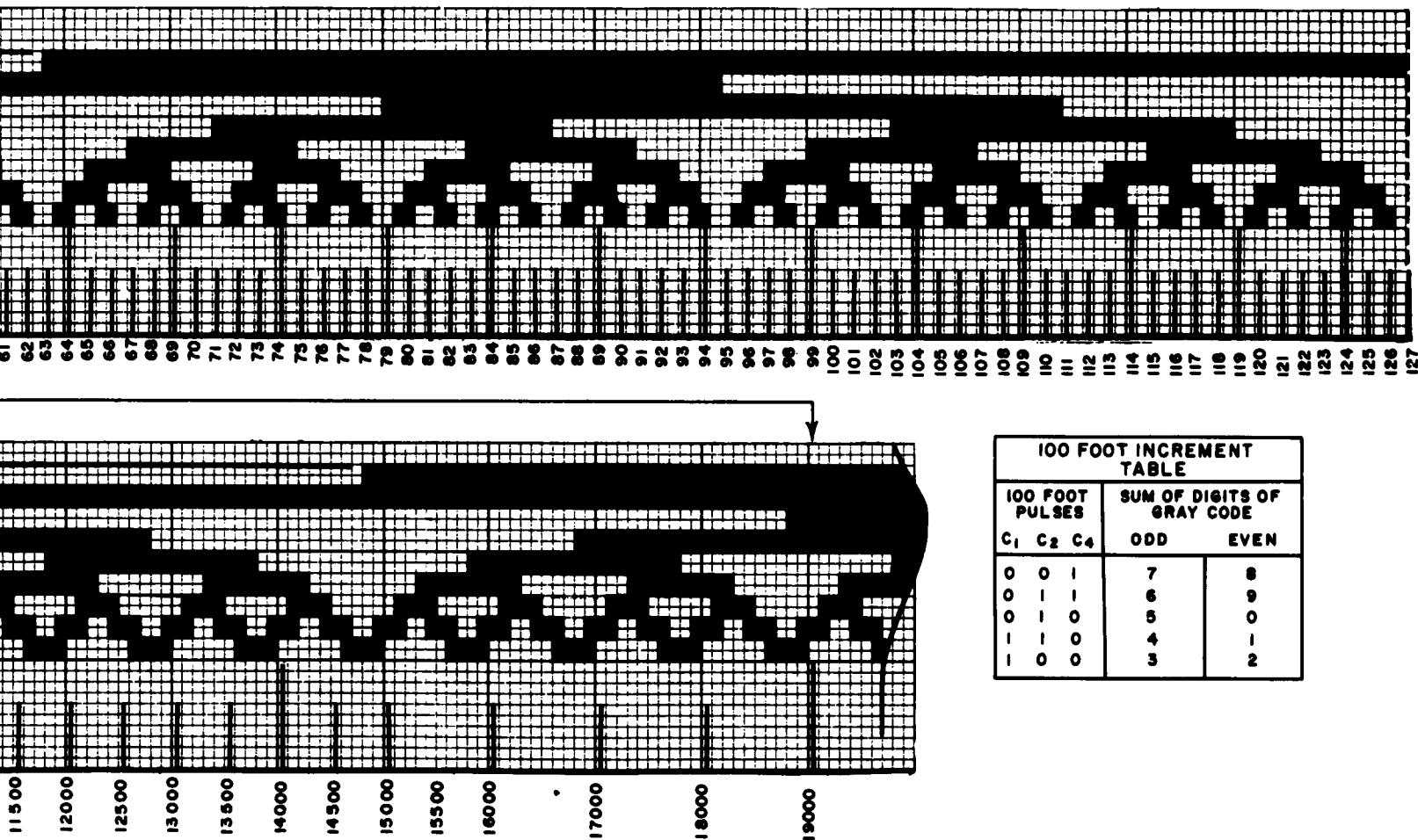Giving altitude from -1000 feet to 127,000 feet.

ALTITUDE TELEMETRY CODE

Append

50
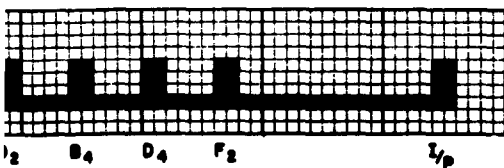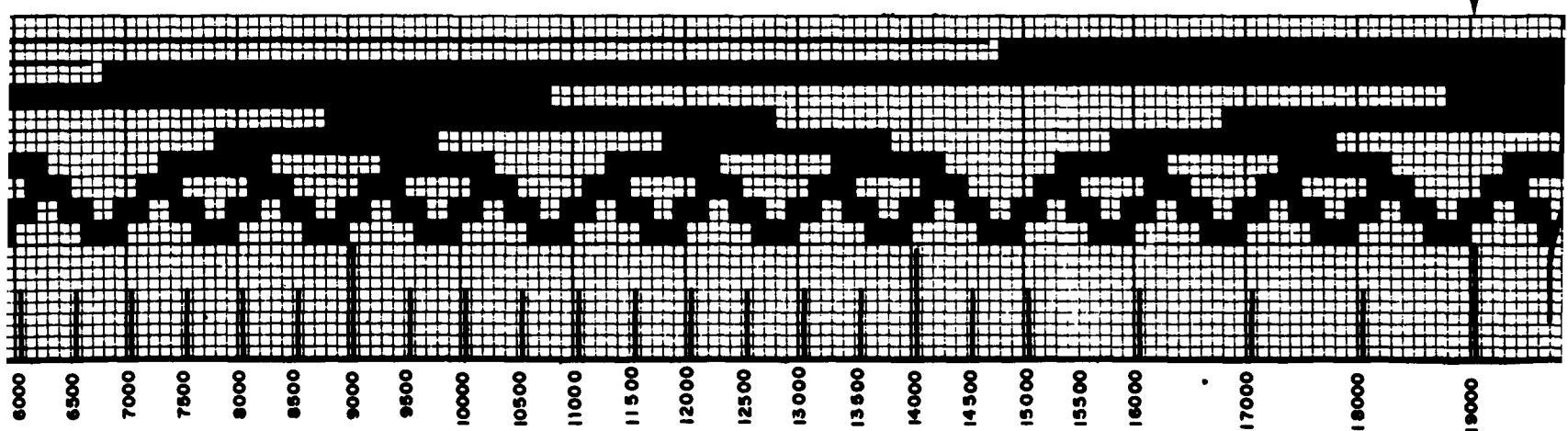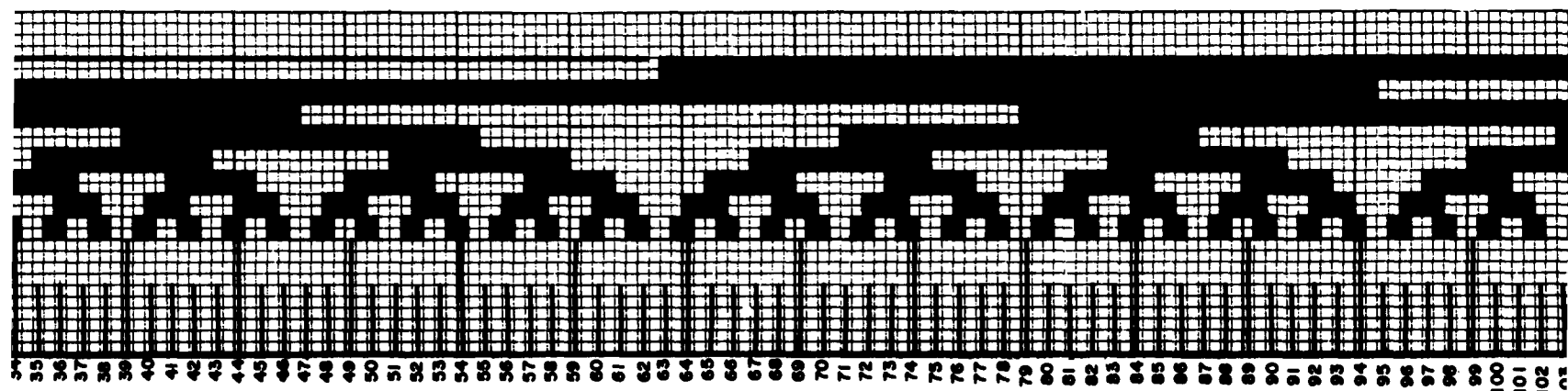
111	1110	1010	1011	1001	1000
10	11	12	13	14	15
21	20	19	18	17	16
42	43	44	45	46	47
53	52	51	50	49	48
74	75	76	77	78	79
85	84	83	82	81	80
06	107	108	109	110	111
17	116	115	114	113	112
38	139	140	141	142	143
49	148	147	146	145	144
70	171	172	173	174	175
81	180	179	178	177	176
02	203	204	205	206	207
13	212	211	210	209	208
34	235	236	237	238	239
45	244	243	242	241	240

256 Increments (500 foot each)
Giving altitude from -1000 feet to 127,000 feet

100 FOOT INCREMENT TABLE		
100 FOOT PULSES C_1 C_2 C_4	SUM OF DIGITS OF GRAY CODE	
	ODD	EVEN
0 0 1	7	8
0 1 1	6	9
0 1 0	5	0
1 1 0	4	1
1 0 0	3	2

Appendix A

50

ALTITUDE TELEMETRY CODE

Appendix B

C-58 Solar Cell Characteristics

Hoffman solar cells have long lifetimes, high temperature stability and very fast response times (20 microseconds). The upper curve, on the following page, shows the current-voltage characteristics for various light energy levels and the lower curve the output variation with temperature. The characteristics of the C-58 cell follow:

1. Length, 0.197 (+0.005 - 0.010) inches.

2. Width, 0.088 (±0.005) inches.

3. Thickness, 0.025 (±0.0010) inches.

4. Active area, 0.014 square inches.

5. Output at 10,000 foot-candles and 400 millovolt load voltage

   a. Average current, 1.65 milliamps.

   b. Average power, 0.67 milliwatts.

6. Average short circuit current at 10,000 foot-candles, 2.1 milliamp.

7. Average open circuit voltage at 10,000 foot-candles, 550 millivolts.

8. Above characteristics are for 25°C. (5°).

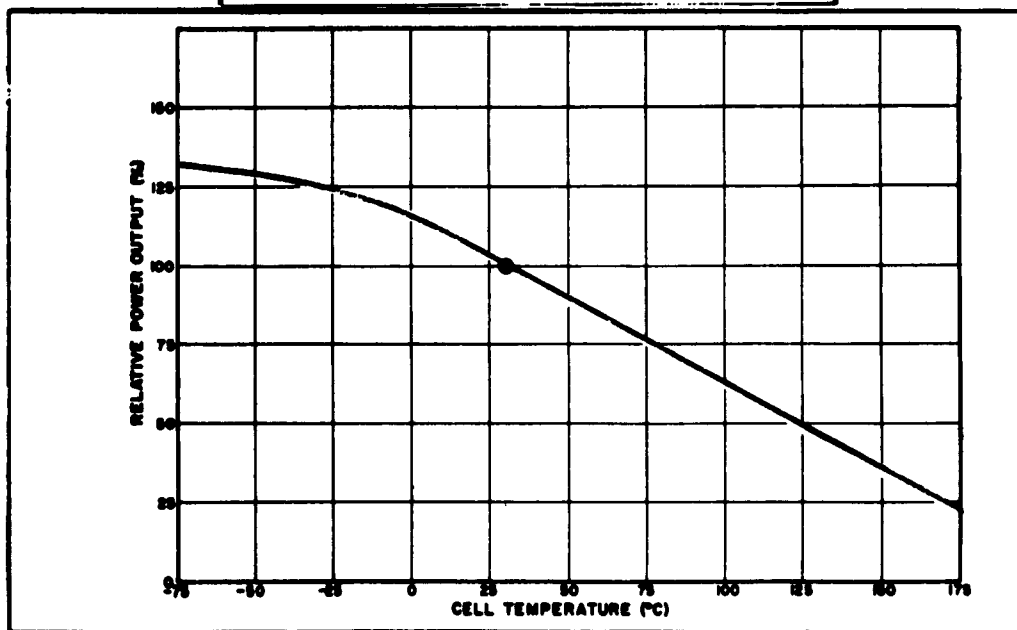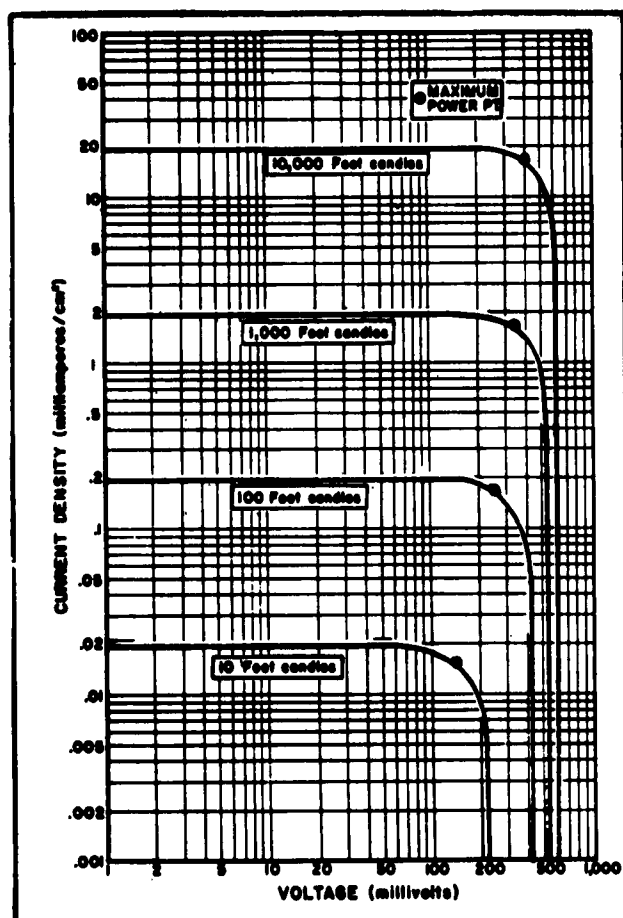9. Operating temperature range -65 to 175°C.

Figure 17   Solar Cell Curves

Appendix C

Altimeter Calibration Data

Standard	Instrument, up	Error	Allowable Error
0	20	20	±50
500	500	0	
1000	970	-30	
1500	1460	-40	
2000	1960	-40	
2500	2480	-20	
3000	2980	-70	
4000	3920	-80	
5000	4940	-60	±150
6000	5920	-80	
7000	6880	-120	
8000	7870	-130	
9000	8850	-150	
10000	9840	-160	±225
11000	10870	-130	
12000	11810	-190	
13000	12820	-180	
14000	13770	-230	
15000	14770	-230	±275
16000	15760	-240	
18000	17760	-240	
20000	19750	-250	±300

Standard	Instrument, down	Error	Allowable Error
15000	14810	-190	±275
13000	12870	-130	
11000	10920	-80	
10000	9920	-80	±225
9000	8960	-40	
8000	7970	-30	
7000	6970	-30	
6000	6000	0	
5000	5010	10	±150
4000	4010	10	
3000	3030	30	
2000	2030	30	
1000	1040	40	
500	540	40	
0	40	40	± 50
-500	-450	50	

Note: This calibration was accomplished on the E-4 Differential and Absolute Pressure Manometer Manufactured by the Ideal Laboratory and Supply Company (see photo next page).
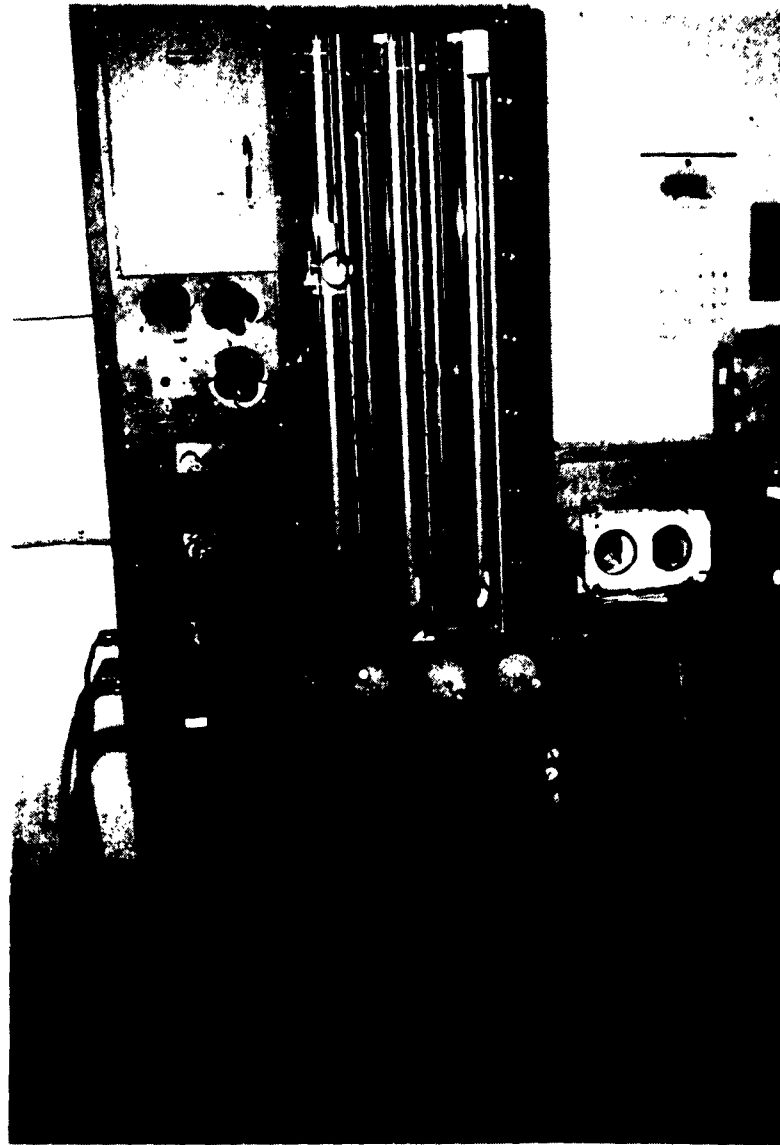
Figure 18 Altimeter Calibration Manometer

Appendix D

Estimated Costs of Altimeter Conversion

1. Solar cells, premounted and wired $12.00

2. Conversion gears and plate. 7.00

3. Special adjustable, focusable, instrument lights. . . 10.00

4. Encoding disc 50

5. Plastic indicator hand 50

6. Glass dial face 25

7. Case electrical connector 1.75

8. Labor, 6 hours at $3.00/hr. 18.00

9. Total $50.00

Appendix E

Logic Circuit Specifications

Unit Number

1004   Astable Multivibrator (Pulse Generator)

     a. Basic Circuit: Multivibrator

     b. Input: None

     c. Output: 0.1 microsecond pulses with ±10 to ±32 volts amplitude. Frequency variable from 15 to 750 kc.

1101   Bistable Multivibrator (Flip Flop)

     a. Basic Circuit: Eccles-Jordan

     b. Inputs: Zero, One, Complement; 0.1 microsecond at a minimum of 12 volts.

     c. Outputs: Zero, One; -23 or zero volts.

1201   Coincidence Detector ("and" gate)

     a. Basic Circuit: Tube Gate

     b. Inputs: 1. 0.1 microsecond pulses at minimum voltage of 13 volts on grid number 1.

               2. Zero volts or an open circuit on grid number 3 allows output. Minus 8 volts or more on grid number 3 inhibits the output.

1301   Pulse Delay

     a. Basic Circuit: Monostable Multivibrator

        b. Input: Positive 0.1 microsecond pulses at $\pm$10 to $\pm$32 volts.

        c. Output: 1. 0.1 microsecond pulses at $\pm$10 to $\pm$32 volts.

                2. Delay voltage, 30 volt pulse. Rise time 0.05 microseconds.

        d. Delay Range: One to 80,000 microseconds.

1302   Pulse Delay

        a. Basic Circuit: Tapped Delay Line

        b. Input: 0.1 microsecond pulses with 13 volt minimum amplitude.

        c. Output: 0.1 microsecond to 1.9 microsecond steps.

1402   Channel Selector (4 Coincidence Detectors)

        Specifications: Same as unit 1201 except that 4 outputs are available with amplitude controls.

1501   Pulse Gater (Multivibrator and Coincidence Gate)

        Specifications: A combination of units 1301 and 1201; however, no pulse output is available from the multivibrator. The gating pulse is continuously adjustable from 0.3 microseconds to 5,000 microseconds.

1601   Mixer ("or" gate)

        a. Basic Circuit: Crystal Diodes

        b. Input: 0.1 microsecond pulses at five separate connectors.

        c. Output: 0.1 microsecond pulses with maximum attenuation of one db.

1901   Inverter

   a. Basic Circuit: D-C Coupled Amplifier

   b. Inputs: Zero or -5 to -23 volts.

   c. Output: Zero volts when the input is -5 to
       -23 volts or no signal is applied, -23 volts
       with zero volts input.

3003   Negative Current Driver

   a. Basic Circuit: Cascode amplifiers

   b. Inputs: 15 to 30 volt 0.1 microsecond pulse.

   c. Output: One ampere pulses with variable rise
       time and duration.

Note: Circuit schematics corresponding to the above units are available
from the Burroughs Corporation.

Vita

James A. Schmitendorf was born on 28 November 1933 in Baldwin, Kansas, the son of George Dewey Schmitendorf and Grace Marie (Keller) Schmitendorf. Upon graduation from high school he enrolled in the University of Kansas in the fall of 1951. In June 1956 he received his Bachelor of Science Degree in Electrical Engineering and his reserve commission as a Lieutenant in the USAF.

After graduation he worked for McDonnell Aircraft Corporation in St. Louis as an engineer in the systems division. In August 1956 he entered the service at San Antonio for pre-flight orientation. In November 1957 he graduated from basic jet pilot training school at Webb AFB, Texas. For three years prior to his coming to AFIT he was assigned to the 4650th Combat Support Squadron at Richards-Gebaur AFB, Missouri where he flew C-123 and C-54 aircraft for the Air Defense Command. While at Richards-Gebaur he spent some time as operations officer of the Base Aero Club.

He has 3,000 hours of flying experience in several types of aircraft and is a graduate of the Air Force Instrument Pilot Instructor School at Waco, Texas. He is presently an Instrument Flight Examiner at Wright-Patterson AFB, Ohio.

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